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UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

SAN JOSE DIVISION

BOOKHAM, INC., a Delaware corporation, Plaintiff, v. JDS UNIPHASE CORP., a Delaware corporation; AGILITY COMMUNICATIONS, INC., a Delaware corporation, and DOES 1-10, Defendants.	C08 01275 HRL **COMPLAINT FOR INTENTIONAL INTERFERENCE WITH PROSPECTIVE ECONOMIC ADVANTAGE, STATUTORY UNFAIR COMPETITION AND DECLARATORY JUDGMENT OF NONINFRINGEMENT, INVALIDITY AND UNENFORCEABILITY** **DEMAND FOR JURY TRIAL**

Plaintiff, for its complaint herein, alleges as follows:

THE PARTIES

1. Plaintiff, Bookham, Inc. ("Bookham") is a corporation organized and existing under the laws of the State of Delaware, with its principal place of business at 2584 Junction Ave., San Jose, California, 95134.

2. Defendant JDS Uniphase Corp. ("JDSU") is a corporation organized and existing under the laws of the State of Delaware, with its principal place of business at 430 N. McCarthy Boulevard, Milpitas, California, 95035.

3. Defendant Agility Communications, Inc. ("Agility Communications") is a corporation organized and existing under the laws of the State of Delaware. Agility Communications' address is listed with the California Secretary of State as 475 Pine Avenue, Goleta, California, 93117. Agility Communications' registered agent is located at 430 N. McCarthy Boulevard, Milpitas, California, 95035.

4. The true names or capacities, whether individual, corporate, associate, or otherwise, of defendants named as DOES 1 through 10 inclusive, are unknown to Bookham, and Bookham therefore sues these defendants by fictitious names. Bookham will seek leave to amend this complaint to include the true names and capacities of the DOE defendants when ascertained.

JURISDICTION

5. This is an action under section 17200 *et seq.* of the Business & Professions Code of the State of California. Each of the Defendants is subject to jurisdiction in the State of California because they expressly, intentionally, and knowingly directed unlawful actions at a corporation headquartered in California and because these intentional actions caused harm in California. In addition, JDSU is headquartered in California and specifically in the Northern District of California.

6. This is also an action arising under the laws of the State of California in which Bookham seeks to recover for intentional interference with economic advantage. Each of the Defendants is subject to jurisdiction in the State of California because they expressly, intentionally, and knowingly directed actions at a corporation headquartered in California and because these intentional actions caused harm in California.

7. This is also an action for a declaratory judgment of noninfringement, invalidity and unenforceability of United States Patents Nos. 6,658,035, 6,654,400, and 6,687,278 and related patents. The action arises under the Declaratory Judgment Act, 28 U.S.C. §§2201-2202 and the patent laws of the United States, including Title 35, United States Code. This Court has original

jurisdiction over the subject matter of this action under 28 U.S.C. §1338.

VENUE

8. Venue is proper in this Court under 28 U.S.C. §1391.

INTRADISTRICT ASSIGNMENT

9. This patent action is in an excepted category for Local Rule 3-2(c), Assignment of a Division, and will be assigned on a district-wide basis.

JDSU'S WRONGFUL ALLEGATIONS OF PATENT INFRINGEMENT

10. JDSU purports to own United States Patent Nos. 6,658,035 (the " '035 patent"), 6,654,400 (the " '400 patent"), and 6,687,278 (the " '278 patent"), collectively referred to as the "Patents" and attached as Exhibits 1, 2 and 3. Records at the United States Patent and Trademark Office list Agility Communications as the present assignee for the Patents.

11. JDSU acquired Agility Communications in November 2005 and, on information and belief, acquired at least some rights in the Patents.

12. JDSU asserts that the technology covered by the Patents is proliferating through the optics industry.

13. In particular, JDSU asserts that Bookham's tunable laser products, which are used for high-speed data communications, are covered by the '035 patent.

14. The '400 patent and the '278 patent are related to the '035 patent and claim related subject matter to the '035 patent.

15. JDSU has accused Bookham in writing of infringing the claims of the '035 patent.

16. In particular and on information and belief, JDSU has informed Bookham's customers that Bookham's tunable laser products infringe the claims of the '035 patent.

17. Additionally, and on information and belief, JDSU has informed Bookham's customers that they will infringe the claims of the '035 patent by purchasing or using Bookham's tunable laser products.

18. JDSU, on information and belief, has informed Bookham customers that Bookham tunable lasers may not be available in the future due to the fact that those products infringe the '035 patent.

19. JDSU's assertions of infringement have damaged Bookham.

20. JDSU's threat to Bookham's customers has negatively impacted Bookham's sales and interaction with its customers.

21. JDSU, on information and belief, has offered to sell its products to Bookham's customers as a replacement for Bookham's products.

22. Additionally, Bookham has suffered irreparable injury, including increased transactional costs, damage to its corporate reputation, and damage to its brand as a result of JDSU's conduct.

FIRST CLAIM FOR RELIEF

INTENTIONAL INTERFERENCE WITH PROSPECTIVE ECONOMIC ADVANTAGE

UNDER CALIFORNIA COMMON LAW

23. Bookham incorporates paragraphs 1-22 as though set forth fully and completely herein.

24. On information and belief, JDSU intentionally interfered with prospective economic relations between Bookham and its potential customers.

25. On information and belief, JDSU has engaged in unfair, unlawful or fraudulent business practices, and in untrue or misleading advertising through accusing the Bookham tunable laser products of infringing the claims of the '035 patent.

SECOND CLAIM FOR RELIEF

STATUTORY UNFAIR COMPETITION UNDER CALIFORNIA BUSINESS AND PROFESSIONAL CODE

§ 17200, ET SEQ.

26. Bookham incorporates paragraphs 1-22 as though set forth fully and completely herein.

27. On information and belief, JDSU has engaged in unfair, unlawful or fraudulent business practices, and in untrue or misleading advertising by accusing the Bookham tunable laser products of infringing the claims of the '035 patent.

28. On information and belief, JDSU's unlawful conduct has resulted in JDSU's unjust enrichment.

29. Upon information and belief, JDSU is likely to continue its allegations of patent infringement unless enjoined by this Court.

30. Bookham is entitled to an injunction enjoining JDSU from making any threats of or charging or asserting or instituting any action for infringement of the claims of the Patents against Bookham, or anyone in privity with Bookham, including its suppliers, successors, assigns, agents, customers, and/or potential customers.

31. Bookham has suffered monetary damages resulting from JDSU's unlawful conduct.

THIRD CLAIM FOR RELIEF

DECLARATORY JUDGMENT OF NONINFRINGEMENT OF U.S. PATENT NOS. 6,658,035, 6,654,400, AND 6,687,278

32. Each of paragraphs 1-22 is incorporated herein by reference.

33. There is an actual and justiciable controversy between Bookham and JDSU as to whether the use, making, sale, or offering for sale of the Bookham tunable laser products infringes the claims of the '035, '400, and '278 patents.

34. On information and belief, JDSU has accused Bookham's tunable laser products of infringing the claims of the '035 patent.

35. The '400 and '278 patents are related to the '035 patent and claim related subject matter to the '035 patent.

36. Bookham currently manufactures the Bookham tunable laser products for sale and use in the United States.

37. Bookham's tunable laser products do not infringe any valid claim of the '035, '400 and '278 patents.

38. JDSU's allegations of patent infringement have caused, and will continue to cause, damage to Bookham.

39. Upon information and belief, JDSU is likely to continue its allegations of patent infringement.

40. Bookham is entitled to a declaratory judgment of noninfringement of the claims of the '035, '400, and '278 patents.

FOURTH CLAIM FOR RELIEF

DECLARATORY JUDGMENT OF INVALIDITY OF U.S. PATENT NOS. 6,658,035, 6,654,400, AND 6,687,278

41. Each of paragraphs 1-22 is incorporated herein by reference.

42. There is an actual and justiciable controversy between Bookham and JDSU as to whether each and every claim of the '035, '400, and '278 patents is valid.

43. Bookham contends that one or more claims of the '035, '400, and '278 patents is invalid for failure to meet one or more of the conditions of patentability specified in 35 U.S.C. §§101, 102, 103 and/or 112.

44. On information and belief, JDSU contends that each claim of the '035, '400, and '278 patents is valid and enforceable.

45. The assertions made by JDSU that Bookham is infringing the '035 patent have caused, and will continue to cause, irreparable harm to Bookham.

46. Bookham is entitled to a declaratory judgment of invalidity of the claims of the '035, '400, and '278 patents.

FIFTH CLAIM FOR RELIEF

DECLARATORY JUDGMENT OF UNENFORCEABILITY OF U.S. PATENT NOS. 6,658,035, 6,654,400, AND 6,687,278 AND RELATED PATENTS AND PATENT APPLICATIONS

47. Each of paragraphs 1-22 is incorporated herein by reference.

48. There is an actual and justiciable controversy between Bookham and JDSU as to whether the '035, '400, and '278 patents and/or related patents and patent applications are unenforceable in whole or in part due to inequitable conduct before the United States Patent and Trademark Office (the "USPTO") by person(s) involved in the prosecution of the '035, '400, and '278 patents and/or related patents and patent applications.

49. Bookham contends that one or more claims of the '035, '400, and '278 patents and/or related patents and patent applications are unenforceable because of failure to comply with the duty of candor to the USPTO during the prosecution of the applications that led to the issuance

of the '035, '400, and '278 patents, related applications, and applications upon which priority is claimed.

50. Upon information and belief, person(s) involved in the prosecution of the '035, '400, and '278 patents and/or related patents and patent applications violated the duty of candor with the intent to deceive the USPTO during the prosecution of the '035, '400, and '278 patents and/or related patents and patent applications.

51. Under the doctrine of infectious unenforceability, the inequitable conduct committed by person(s) involved in the prosecution of the '035, '400, and '278 patents and/or related patents and patent applications infects and renders unenforceable all related patents and patent applications.

52. Bookham is entitled to a declaratory judgment of unenforceability of the claims of the '035, '400, and '278 patents and/or related patents and patent applications.

WHEREFORE, Bookham prays that:

(a) Agility, JDSU, its officers, agents, servants, employees, attorneys, assignees, and those persons in active concert or participation with them, be enjoined from making any threats of or charging or asserting or instituting any action for infringement of the '035, '400, and '278 patents against Bookham, or anyone in privity with Bookham, including its suppliers, successors, assigns, agents, customers, and/or potential customers;

(b) Bookham recover compensatory damages against Agility and JDSU;

(c) Bookham recover punitive damages against Agility and JDSU;

(d) A declaratory judgment be entered that the manufacture, use, and/or sale of the Bookham tunable laser products does not infringe, induce the infringement of, or contribute to the infringement of the '035, '400, and '278 patents;

(e) A declaratory judgment be entered that each claim of the '035, '400, and '278 patents is invalid;

(f) A declaratory judgment be entered that each claim of the '035, '400, and '278 patents and, under the doctrine of infectious unenforceability, each claim of related patents and patent applications is unenforceable;

(g) This case be declared an exceptional case under 35 U.S.C. §285, and that Bookham be awarded its attorney's fees in this action; and

(h) Bookham be awarded all other and further relief as the Court deems just and proper in this case.

Dated: March 4, 2006

COOLEY GODWARD KRONISH LLP

By: ______________________
Jeffrey S. Karr

Attorneys for Plaintiff
BOOKHAM, INC.

JURY DEMAND

Plaintiff respectfully requests a jury trial on all issues triable thereby.

Dated: March 4, 2008

COOLEY GODWARD KRONISH LLP

By: ______________________
Jeffrey S. Karr
Attorneys for Plaintiff
Bookham, Inc.

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EXHIBIT 1

US006654400B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.: US 6,654,400 B1**
(45) **Date of Patent: Nov. 25, 2003**

(54) **METHOD OF MAKING A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ (US); **Gregory Fish**, Santa Barbara, CA (US); **Larry Coldren**, Santa Barbara, CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 302 days.

(21) Appl. No.: **09/614,224**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, now Pat. No. 6,580,739, and a continuation-in-part of application No. 09/614,665, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, and a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, now Pat. No. 6,574,259, and a continuation-in-part of application No. 09/614,375, filed on Jul. 12, 2000.

(60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) **Int. Cl.**[7] **H01S 5/026**

(52) **U.S. Cl.** **372/50**; 372/20; 438/22

(58) **Field of Search** 372/20, 50; 438/34, 438/22

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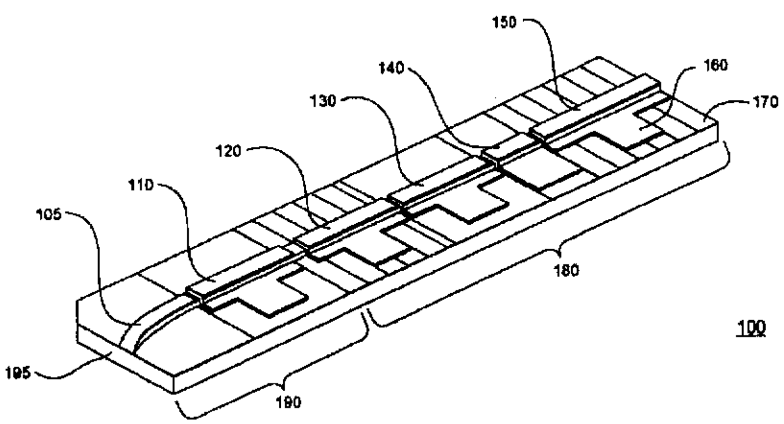
(List continued on next page.)

Primary Examiner—Quyen Leung
Assistant Examiner—Jeffrey Zahn
(74) *Attorney, Agent, or Firm*—Gates & Cooper LLP

(57) **ABSTRACT**

A method of making a diode laser assembly provides a substrate. An epitaxial structure is formed on the substrate. Different areas of the epitaxial structure have different optical properties. A laser, a modulator and a coupler are formed in the epitaxial structure.

76 Claims, 7 Drawing Sheets



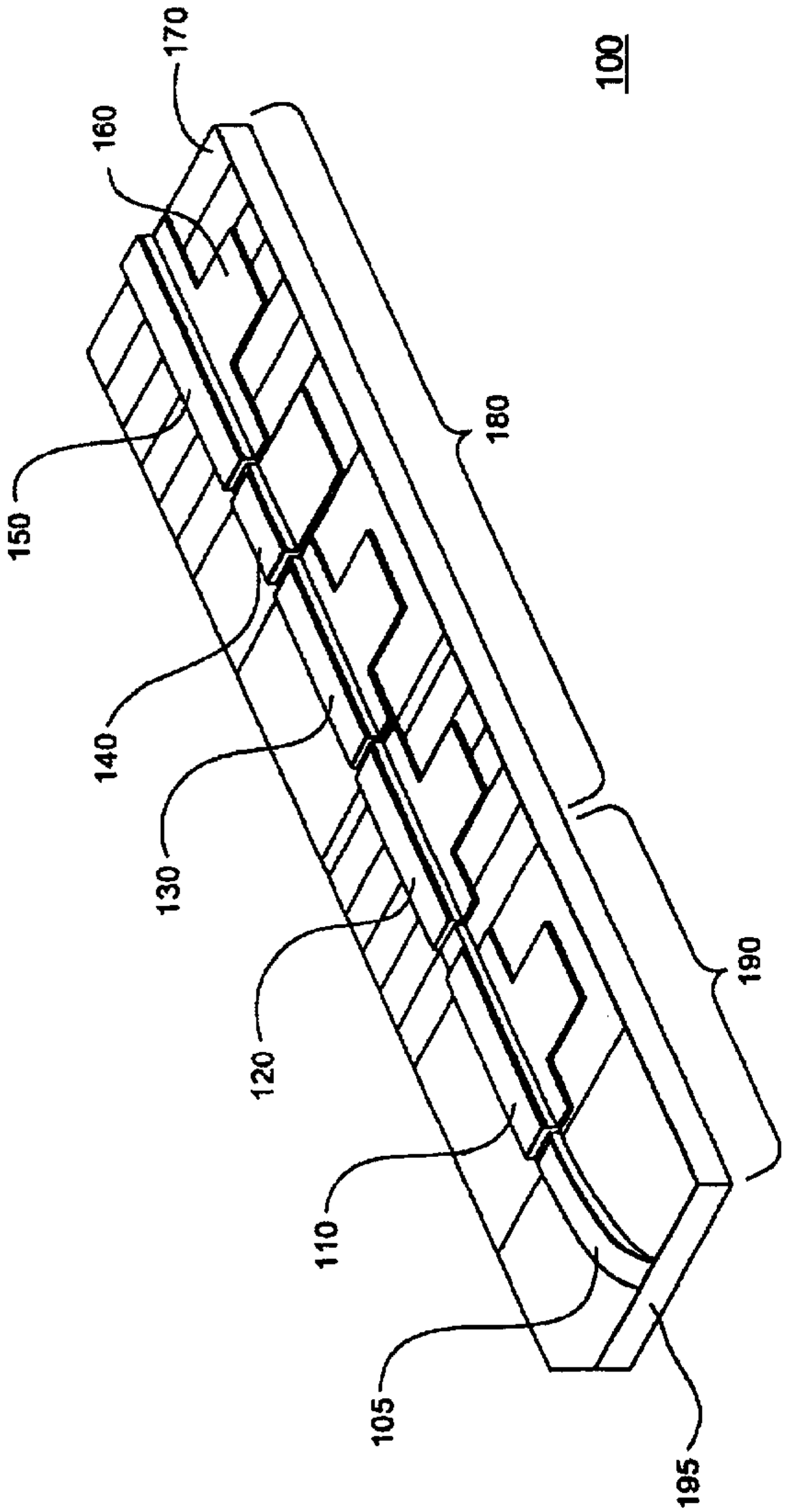


FIG. 1A

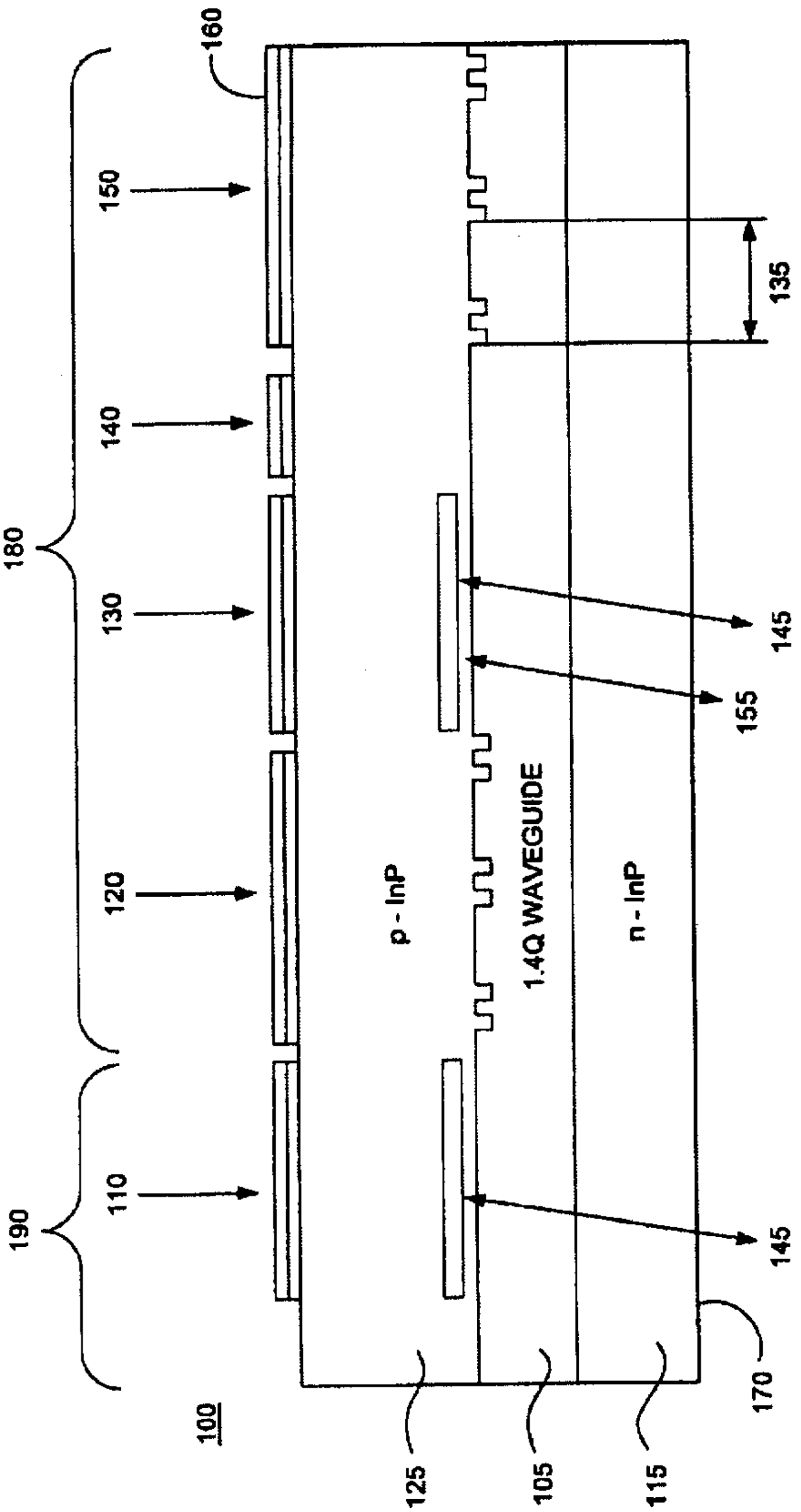

160
150
140
130
120
110
180
190
135
145
155
145
p - InP
1.4Q WAVEGUIDE
n - InP
100
125
105
115
170

FIG. 1B

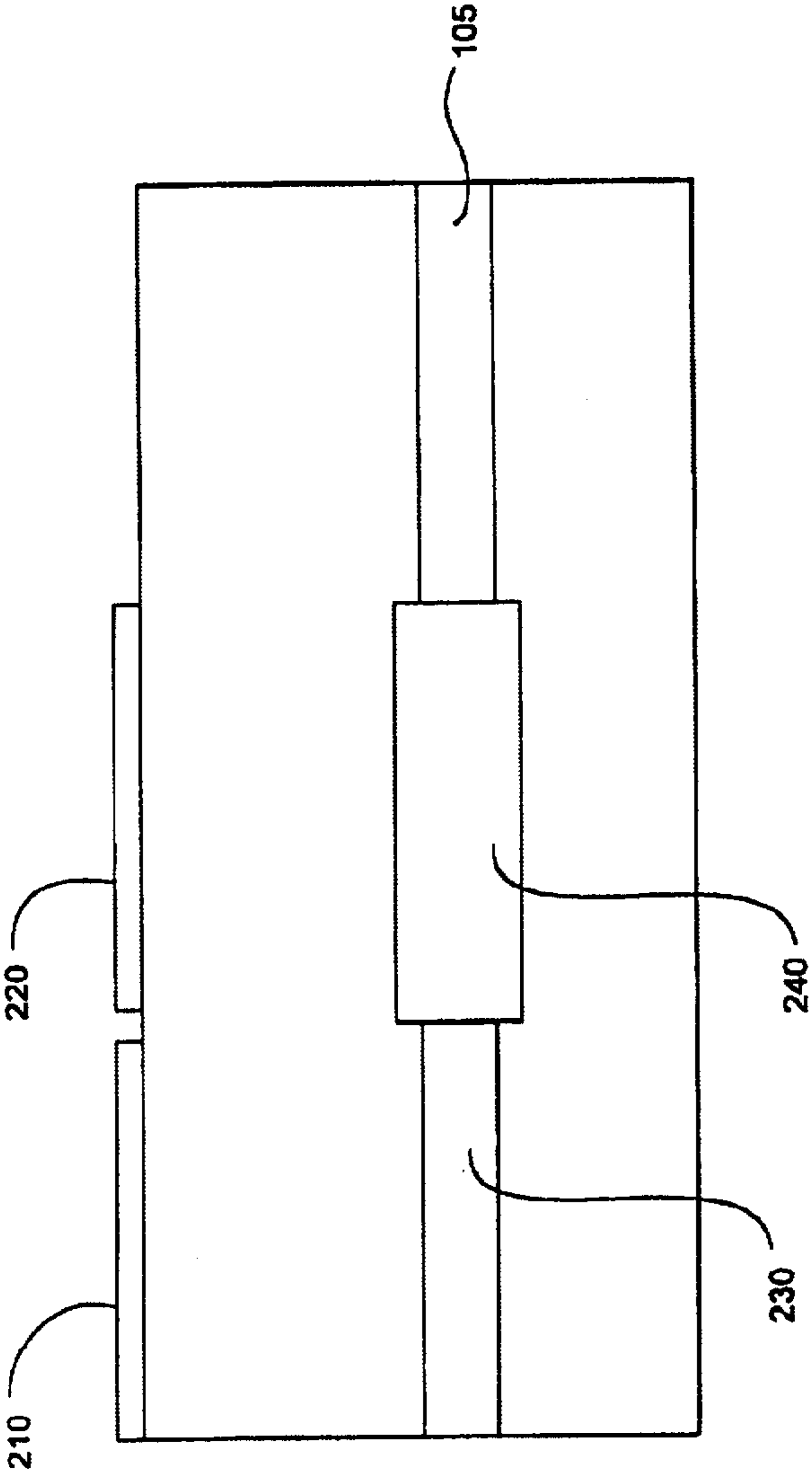


FIG. 2A

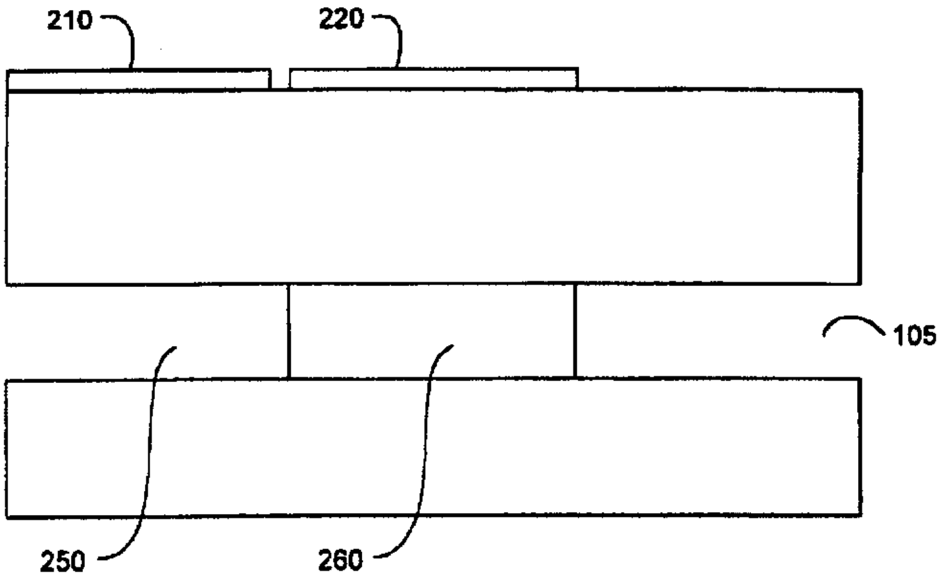


FIG. 2B

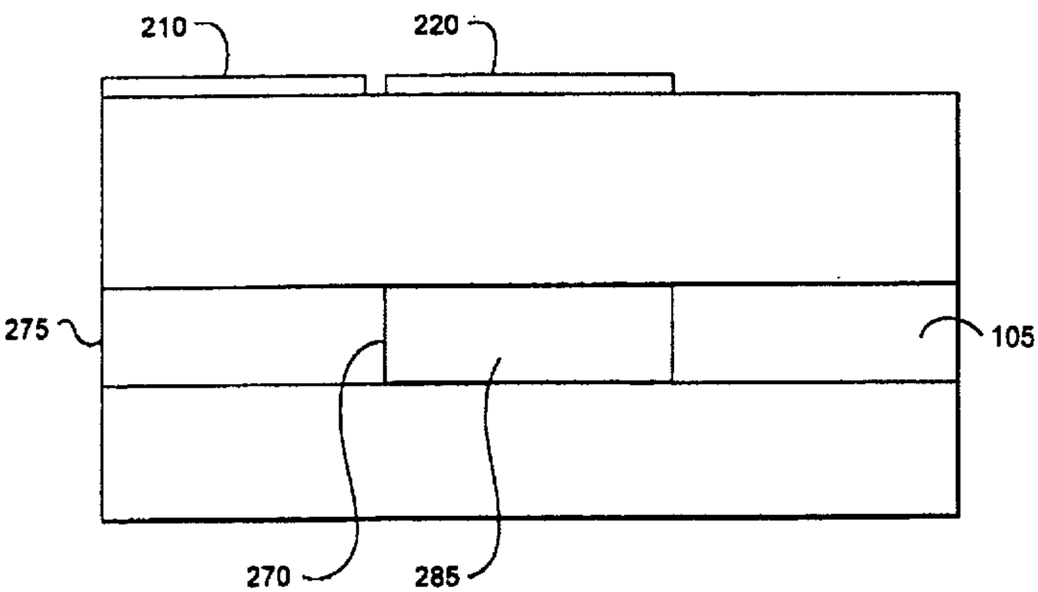


FIG. 2C

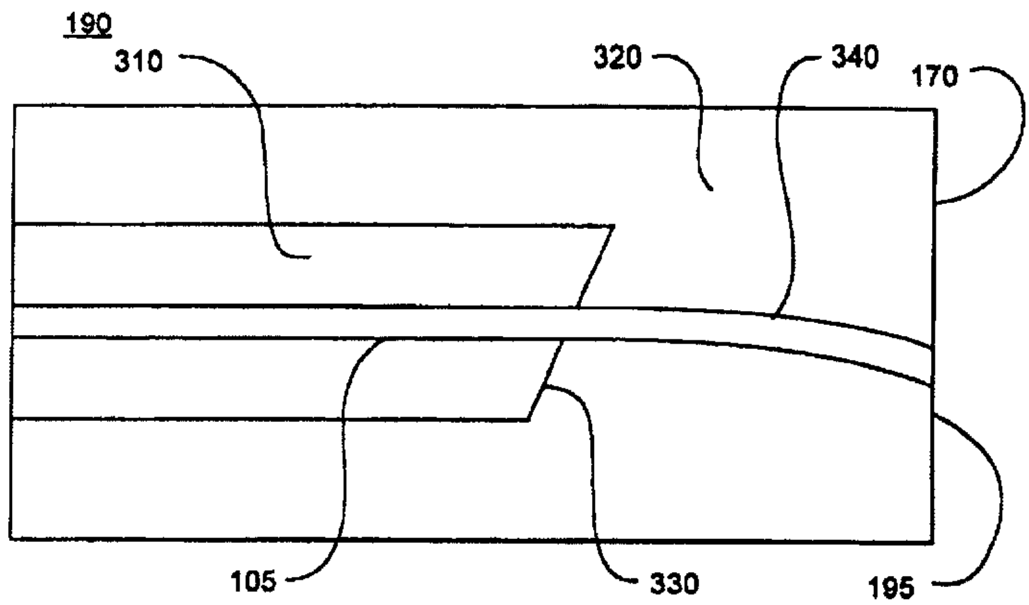


FIG. 3A

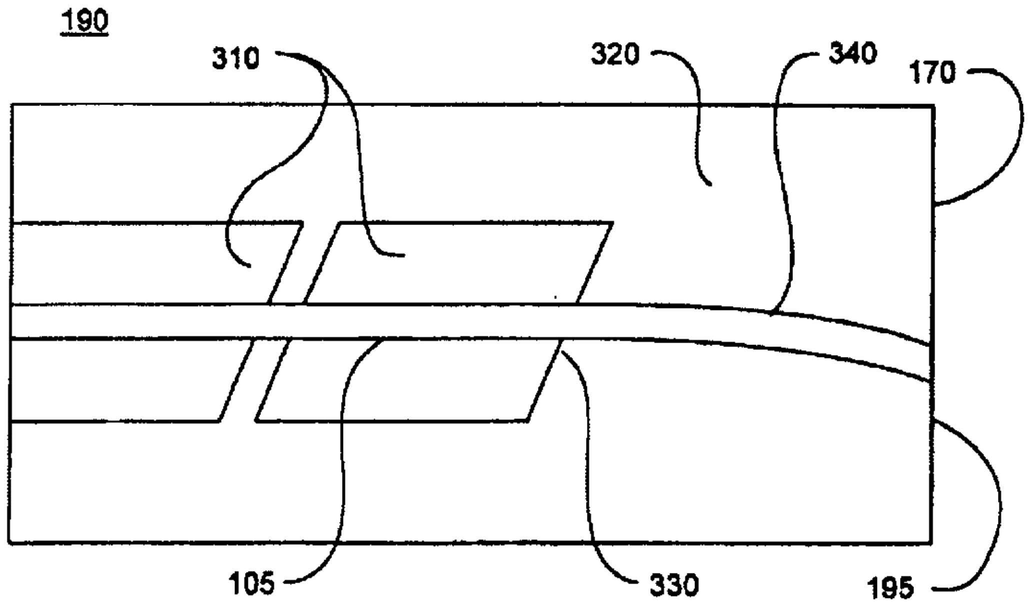


FIG. 3B

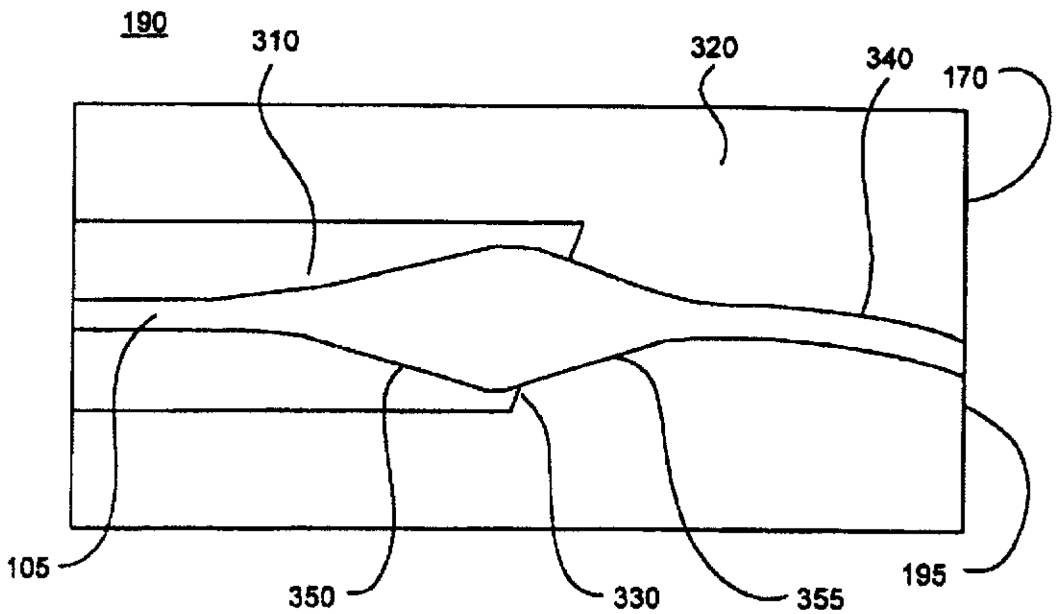


FIG. 3C

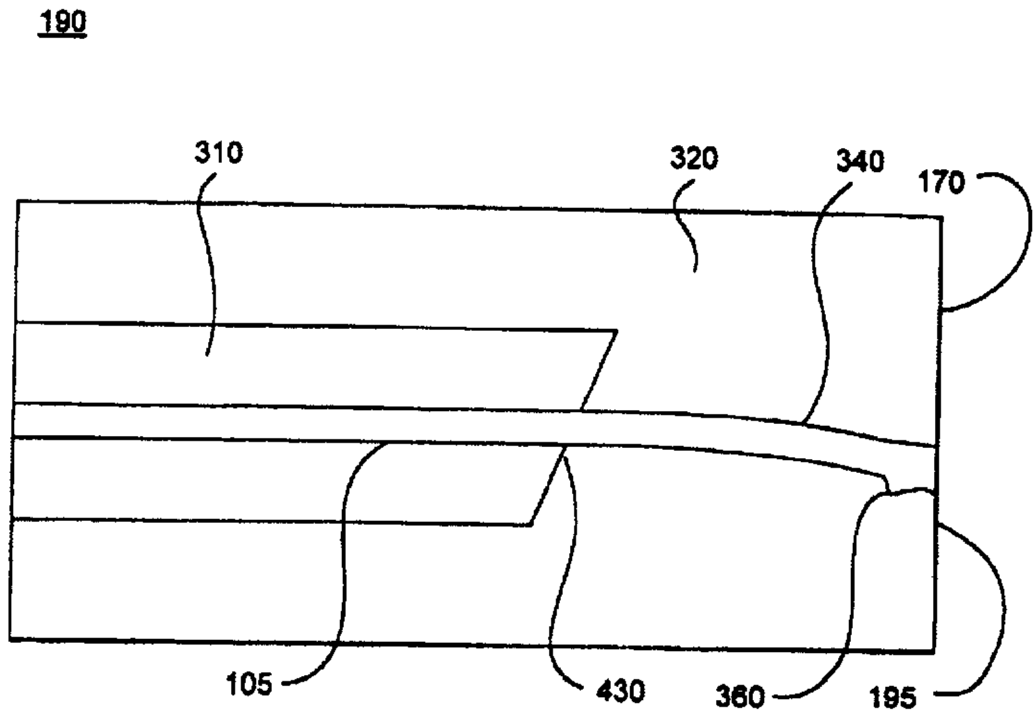


FIG. 3D

METHOD OF MAKING A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part and claims the benefit of priority of U.S. Provisional Application Serial No. 60/152,072, filed Sep. 2, 1999, U.S. Provisional Application Serial No. 60/152,049, filed Sep. 2, 1999, U.S. Provisional Application Serial No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614/377, now U.S. Pat. No. 6,580,739 09/614,895 (now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. Nos. 09/614,674, 09/614,378, 09/614,376, 09/614,195, now U.S. Pat. No. 6,574,259 09/614,375 and 09/614,665, filed on the same date Jul. 12, 2000 which applications are fully incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

BRIEF DESCRIPTION OF THE RELATED ART

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure. The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are nonuniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1A** is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. **1B** is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. **2A** is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. **2B** is a cross-sectional view of the FIG. **2** assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. **2C** is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. **3A** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. **3B** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. **3C** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a flared waveguide.

FIG. **3D** is a cross-sectional view of one embodiment of the FIG. **1** optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. **1A** shows a schematic of an embodiment of the invention. In FIG. **1A**, laser assembly **100**, waveguide **105**,

amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190** and output facet **195** are shown.

In FIG. **1A**, laser assembly **100** comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, and back mirror **150** form a SGDBR-type laser **180** in epitaxial structure **170**. The front and back mirrors define a laser cavity. Amplifier gain section **110** and a portion of waveguide **105** define optical amplifier **190**.

As shown in FIG. **1A**, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure **170** with the laser. Epitaxial structure **170** is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. **1** are gain sections **110** and **130**, phase control section **140** and mirrors **120** and **150**. An example of an optically passive section is the portion of waveguide **105** proximal to output facet **195**.

According to the invention, at least a portion of laser **180** and optical amplifier **190** share a common waveguide **105**. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. **1A**, amplifier **190** is external to the resonant cavity of laser **180** formed by mirrors **120** and **150**. Moreover, amplifier gain section **110** is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. **1A**, optical amplifier **190** has an active section and a passive section. The active section, amplifier gain section **110**, is substantially straight. The passive section of waveguide **105** is curved and intersects output facet **195** at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier **190** and laser **180**.

FIG. **1B** shows a longitudinal cross section of a laser assembly **100** of FIG. **1A**. In FIG. **1B**, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190**, output facet **195**, p type semiconductor layer **125**, n-type semiconductor layer **115**, mirror sampling period **135**, offset quantum wells **145** and stop etch layer **155** are shown.

In FIG. 1B waveguide **105** is formed between p-type and n-type semiconductor layers **125** and **115**, respectively. Mirrors **120** and **150** are formed by sample gratings etched in waveguide **105** with sampling period **135**, as is well-understood in the art.

FIG. 1B illustrates the structure resulting from an offset quantum well technique for optically active and passive section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers **145** grown in a region offset from waveguide **105**. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer **155**. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. 2A–2C illustrate cross-sectional structures over a portion of laser assembly **100** (see FIG. **1**) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. **2A** illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. **2A**, optically passive section **210**, optically active section **220**, bandgap-shifted quantum wells **230**, active section quantum wells **240**, and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. **2A**, different portions of waveguide **105** are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. **2B** illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. **2B**, optically passive section **210**, optically active section **220**, disordered wells **250**, active section multiple quantum wells **260**, and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. **2B**, different portions of waveguide **105**, sections **210** and **220**, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. **2C** illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. **1**) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. **2B**, optically passive section **210**, optically active section **220**, active, butt-joint interface **270**, passive waveguide section **275**, active waveguide section **285** and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. **2B**, active waveguide section **285** and passive waveguide section **275** are separated by a distinct large gradient butt-joint interface **270** as a result of the etch removal process.

FIGS. 3A–3D are plan views, illustrating different embodiments of optical amplifier **190** (see FIG. **1**). In FIGS. 3A–3D optical amplifier **190**, waveguide **105**, epitaxial structure **170**, output facet **195**, active amplifier section **310**, passive amplifier section **320**, active-passive junction **330**, curved waveguide portion **340**, flared waveguide portions **350** and **355** and waveguide mode adapter **360** are shown.

In FIG. 3A, optical amplifier **190** has an active amplifier section **310** combined with a passive amplifier section **320**, where the passive amplifier section includes curved

waveguide portion **340**. The curved waveguide portion intersects output facet **195** at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction **330** is preferably oblique to a centerline of waveguide **105** so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction **330** substantially normal to a centerline of the waveguide.

FIG. 3B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. 3B, the amplifier active section is segmented into two amplifier active sections **310** that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. 3C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion **350** increases the amplifier active volume as compared to the embodiment shown in FIG. 3A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section **355** to a narrow waveguide cross-section is positioned in the amplifier optically passive section **320** since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet **195**. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion **340**, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. 3C, active-passive junction **330** is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. 3D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet **195** so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly **100** (see FIG. **1**) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A method of making a diode laser assembly, comprising:

providing a substrate;

forming an epitaxial structure on the substrate, the editorial structure having optically active and optically inactive areas;

forming a laser in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase action, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom; and

forming an amplifier in the epitaxial structure, at least a portion of the laser and amplifier sharing a common waveguide, the tunable laser output being coupled to the amplifier along the common waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

2. The method of claim **1**, wherein the optically active areas of the epitaxial structure are formed using off-set quantum wells.

3. The method of claim **1**, wherein the optically inactive areas are formed by a selective area growth.

4. The method of claim **1**, wherein the optically inactive areas are formed by a selective area growth using a dielectric mask.

5. The method of claim **1**, wherein the optically inactive areas are formed by selective area disordering.

6. The method of claim **1**, wherein the optically inactive areas are formed by butt joint regrowth.

7. The method of claim **1**, wherein the optically inactive areas are formed with multiple quantum well layers grown on top of the waveguide layer.

8. The method of claim **1**, further comprising:

forming areas of different bandgaps in the epitaxial structure.

9. The method of claim **1**, further comprising:

bombarding at least a portion of the epitaxial structure with ions; and

tailoring a bandgap of at least a portion of the epitaxial structure to create the gain section of the laser.

10. The method of claim **9**, further comprising:

annealing at least a portion of the epitaxial structure to diffuse impurities and vacancies in a selected region of the epitaxial structure to determine the region's optical properties.

11. The method of claim **9**, wherein the ions have an energy no greater than about 200 eV.

12. The method of claim **1**, wherein the amplifier includes a first active region and a passive region.

13. The method of claim **12**, wherein the waveguide extends through at least a portion of the amplifier.

14. The method of claim **13**, wherein the waveguide extends through the first active region and the passive region.

15. The method of claim **14**, wherein a distal portion of the waveguide in the amplifier is curved.

16. The method of claim **14**, wherein a distal portion of the waveguide in the amplifier is curved and the amplifier includes a tapered section.

17. The method of claim **14**, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to in output facet.

18. The method of claim **12**, wherein the first active region has a tapered distal face.

19. The method of claim **12**, wherein the amplifier includes a second active region.

20. The method of claim 19, wherein the waveguide includes an active section.

21. The method of claim 20, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

22. The method of claim 20, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

23. The method of claim 19, wherein the first and second active regions are separated by a passive region.

24. The method of claim 23, wherein the first active region has a tapered distal face.

25. The method of claim 24, wherein the second active region has a tapered proximal face.

26. The method of claim 25, wherein the second active region has a tapered distal face.

27. The method of claim 26, wherein the proximal face and the distal face of the second region are parallel.

28. The method of claim 25, wherein the tapered distal face of the first active region is parallel to the tapered proximal face of the second active region.

29. The method of claim 1, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

30. The method of claim 29, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

31. The method of claim 30, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

32. The method of claim 1, wherein at least a portion of the waveguide is non-parallel to an axis of the laser's cavity.

33. The method of claim 1, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

34. The method of claim 1, wherein at least a portion of the waveguide is flared-out in an active section of the amplifier and flared-in in a passive section of the amplifier.

35. The method of claim 1, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet so that it is more closely matched to the mode in an optical fiber that cries the light away from the output facet.

36. The method of claim 35, wherein the waveguide mode adapter includes a section of passive waveguide and the waveguide's cross section is varied to expand the waveguide's optical mode in an adiabatic manner.

37. The method of claim 1, wherein the optical signal is tunable within a range of at least 15 nm.

38. The method of claim 1, wherein at least a portion of the waveguide is tapered.

39. A method of making a diode assembly, comprising:

providing a substrate;

forming a first semiconductor layer and a second semiconductor layer in an epitaxial structure having optically active and optically inactive areas, the first and second semiconductor layers having different dopings; and

forming a first waveguide layer between the first and second semiconductor layers, the first waveguide layer including a waveguide, a first reflector and a second reflector;

forming an optically active medium disposed between the first and second reflectors, the first and second reflectors defining a laser cavity and producing a tunable laser output; and

forming an amplifier in the epitaxial structure, wherein the laser cavity and the amplifier are optically aligned, the tunable laser output being coupled into the amplifier along the waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

40. The method of claim 39, further comprising:

forming areas of different bandgaps in the epitaxial structure.

41. The method of claim 39, further comprising:

bombarding at least a portion of the epitaxial structure with ions; and

tailoring a bandgap of at least a portion of the epitaxial structure to create a gain medium of the laser.

42. The method of claim 41, further comprising:

annealing at least a portion of the epitaxial structure to diffuse impurities and vacancies in a selected region of the epitaxial structure to determine the region's optical properties.

43. The method of claim 41, wherein the ions have an energy no greater than about 200 eV.

44. The method of claim 39, wherein the amplifier includes a first active region and a passive region.

45. The method of claim 44, wherein the waveguide layer includes a waveguide that extends through at least a portion of the amplifier.

46. The method of claim 45, wherein the waveguide extends through the first active region and the passive region.

47. The method of claim 46, wherein a distal portion of the waveguide in the amplifier is curved.

48. The method of claim 46, wherein a distal portion of the waveguide in the amplifier is curved and the amplifier includes a tapered section.

49. The method of claim 46, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

50. The method of claim 45, wherein at least a portion of the waveguide is tapered.

51. The method of claim 44, wherein the amplifier includes a second active region.

52. The method of claim 51, wherein the waveguide includes an active section.

53. The method of claim 52, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

54. The method of claim 52, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

55. The method of claim 51, wherein the first and second active regions are separated by a passive region.

56. The method of claim 55, wherein the first active region has a tapered distal face.

57. The method of claim 56, wherein the second active region has a tapered proximal face.

58. The method of claim 57, wherein the second active region has a tapered distal face.

59. The method of claim 58, wherein the proximal face and the distal face of the second region are parallel.

60. The method of claim 57, wherein the tapered distal face of the first active region is parallel to the tapered proximal face of the second active region.

61. The method of claim 44, wherein the first active region has a tapered distal face.

62. The method of claim 39, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

63. The method of claim 62, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

64. The method of claim 63, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

65. The method of claim 39, wherein at least a portion of the waveguide is non-parallel to an axis of the laser cavity.

66. The method of claim 39, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

67. The method of claim 39, wherein at least a portion of the waveguide is flared-out in an active section of the amplifier and flared-in in a passive section of the amplifier.

68. The method of claim 39, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet so that it is more closely matched to the mode in an optical fiber that carries the light away from the output facet.

69. The method of claim 68, wherein the waveguide mode adapter includes a section of passive waveguide and the waveguide's cross section is varied to expand the waveguide's optical mode in an adiabatic manner.

70. The method of claim 39, wherein the optical signal is tunable within a range of at least 15 nm.

71. The method of claim 39, wherein the optically inactive areas are formed with multiple quantum well layers grow on top of the waveguide layer.

72. The method of claim 39, wherein the optically active areas in the epitaxial structure are formed using off-set quantum wells.

73. The method of claim 39, wherein the optically inactive areas in the epitaxial structure are formed by a selective area growth.

74. The method of claim 39, wherein the optically inactive areas are formed by a selective area growth using a dielectric mask.

75. The method of claim 39, wherein the optically inactive areas are formed by selective area disordering.

76. The method of claim 39, wherein the optically inactive areas are formed by butt joint regrowth.

* * * * *

EXHIBIT 2

US006658035B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.: US 6,658,035 B1**
(45) **Date of Patent: *Dec. 2, 2003**

(54) **TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

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(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 243 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/614,375**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, which is a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,665, filed on Jul. 12, 2000, which is a continuation-in-part of application No. 09/614,224, filed on Jul. 12, 2000.

(60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) **Int. Cl.**[7] **H01S 5/026**
(52) **U.S. Cl.** **372/50**; 372/43
(58) **Field of Search** 372/50, 43

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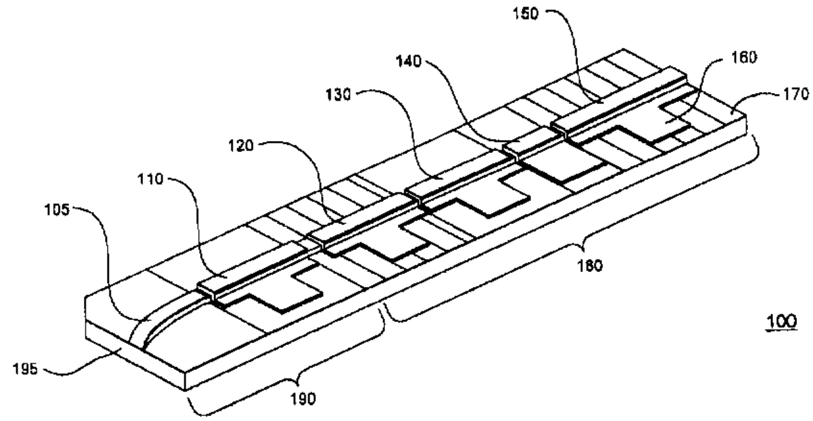
Primary Examiner—Paul Ip
Assistant Examiner—Jeffrey N. Zahn
(74) *Attorney, Agent, or Firm*—Gates & Cooper LLP

(57) **ABSTRACT**

A laser assembly includes an epitaxial structure formed on a substrate. A separately controllable tunable laser resonator and external optical amplifier are formed in the epitaxial structure. At least a portion of the laser and amplifier share a common waveguide, which may have non-uniform optical or geometrical properties along the waveguide centerline or across a normal to the centerline.

82 Claims, 7 Drawing Sheets



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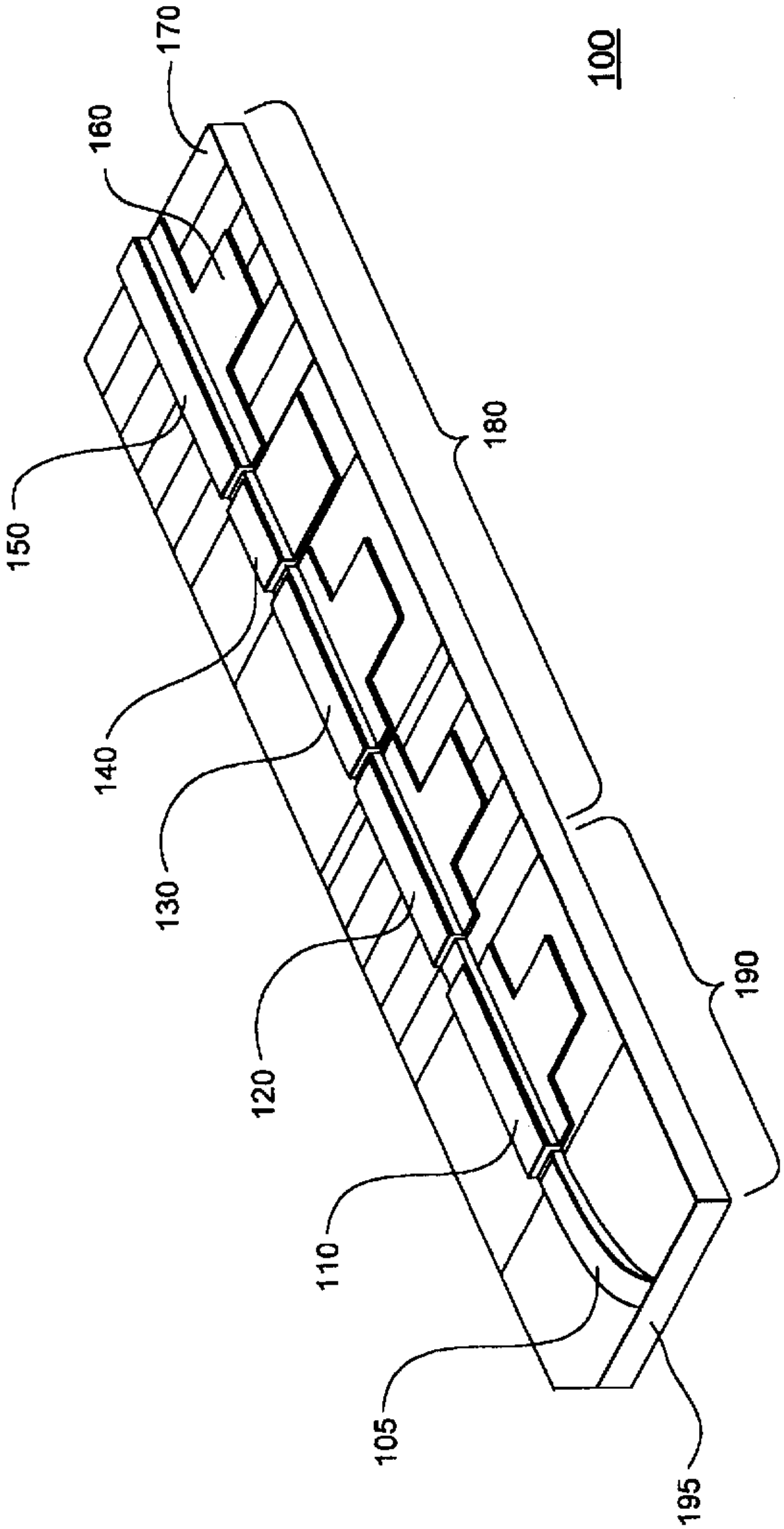
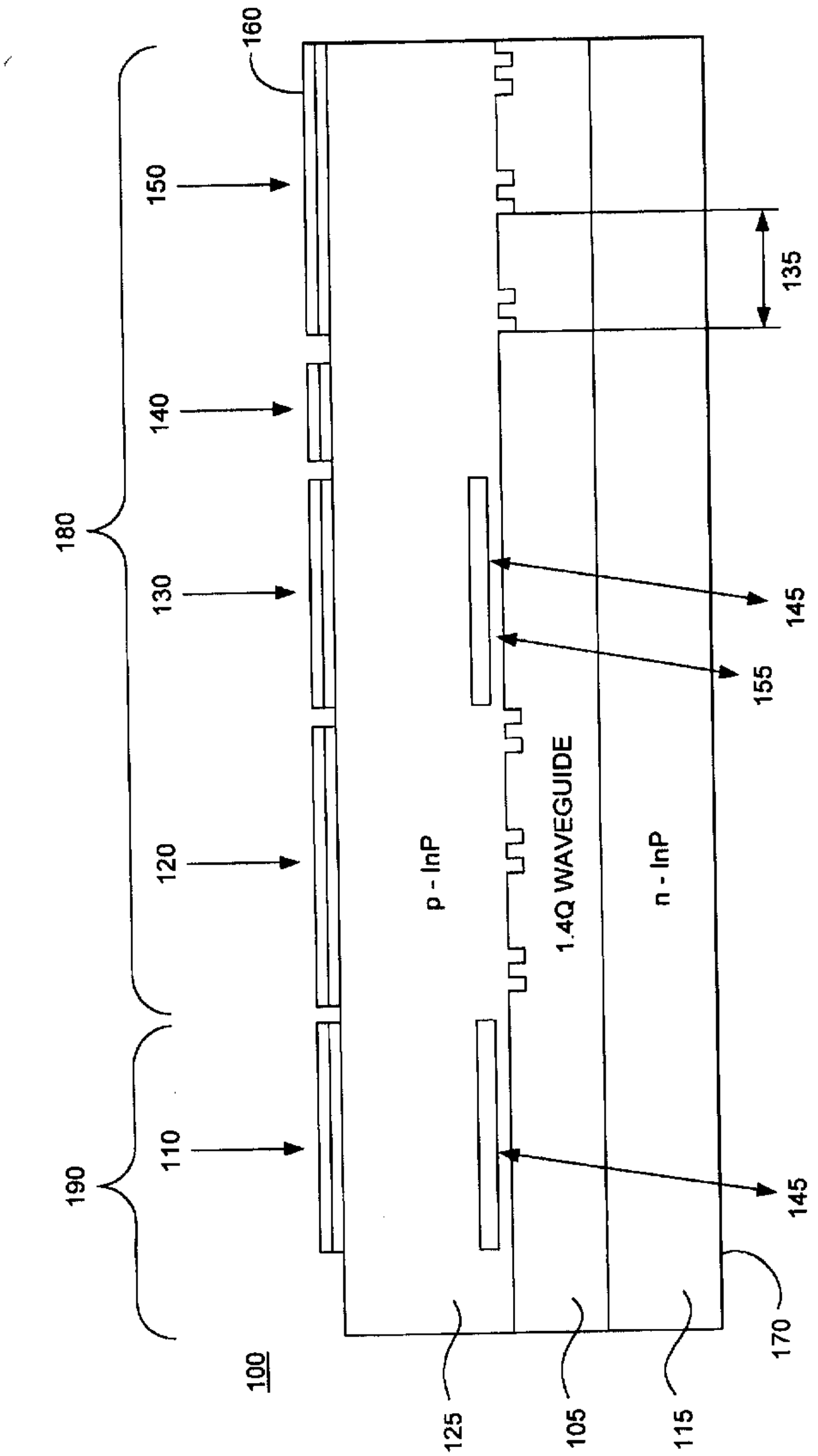


FIG. 1A



160
150
140
130
120
110
180
190
135
145
155
145
p - InP
1.4Q WAVEGUIDE
n - InP
170
100
125
105
115

FIG. 1B

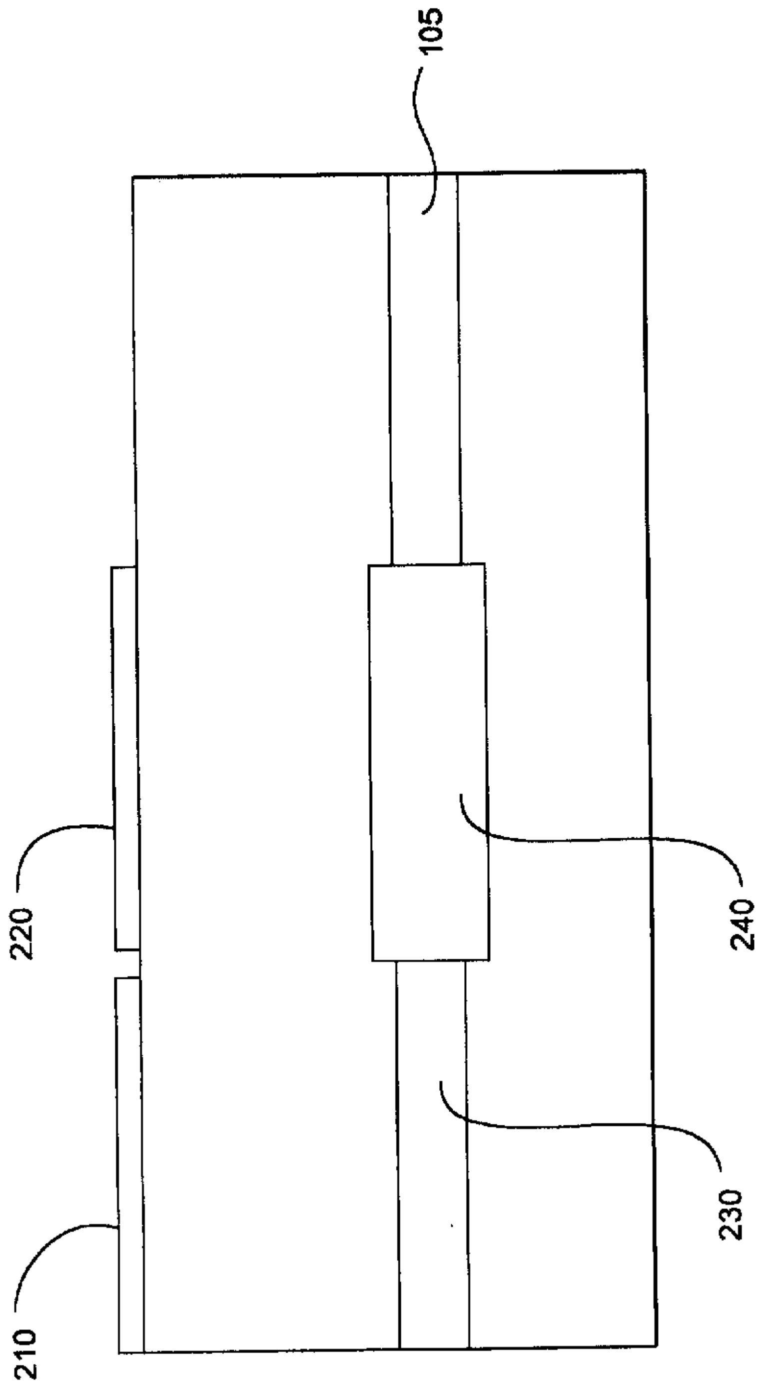


FIG. 2A

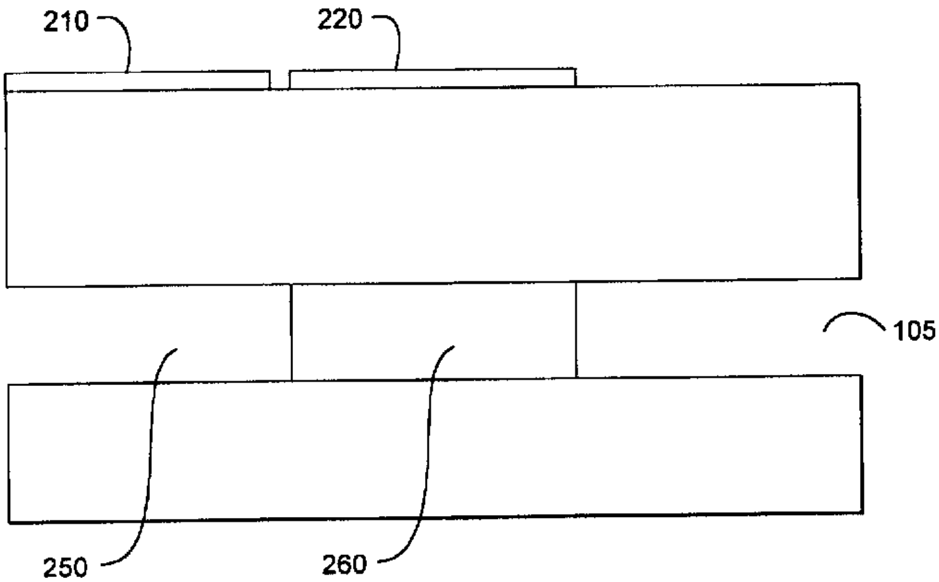


FIG. 2B

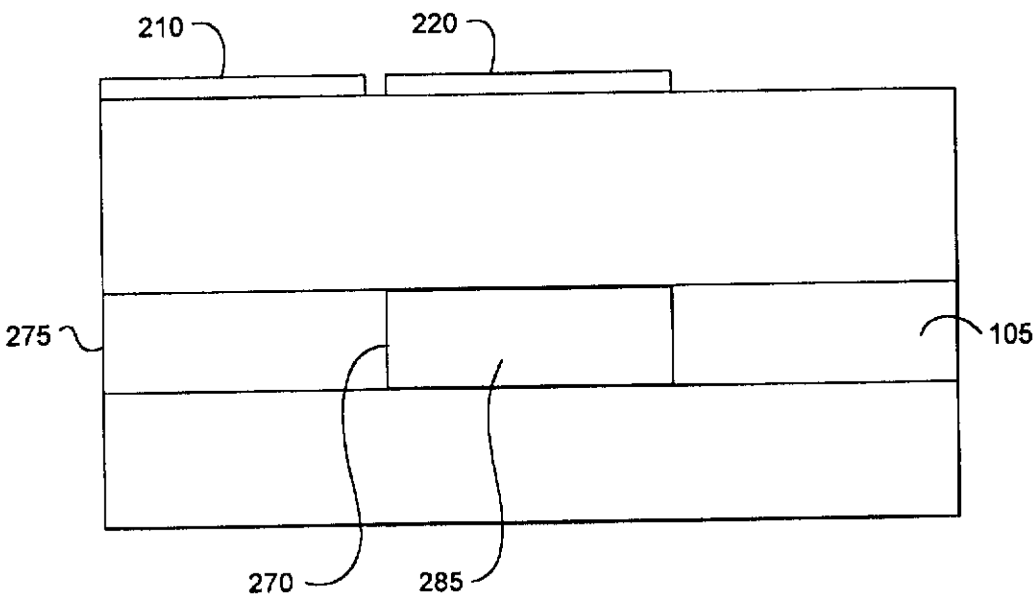


FIG. 2C

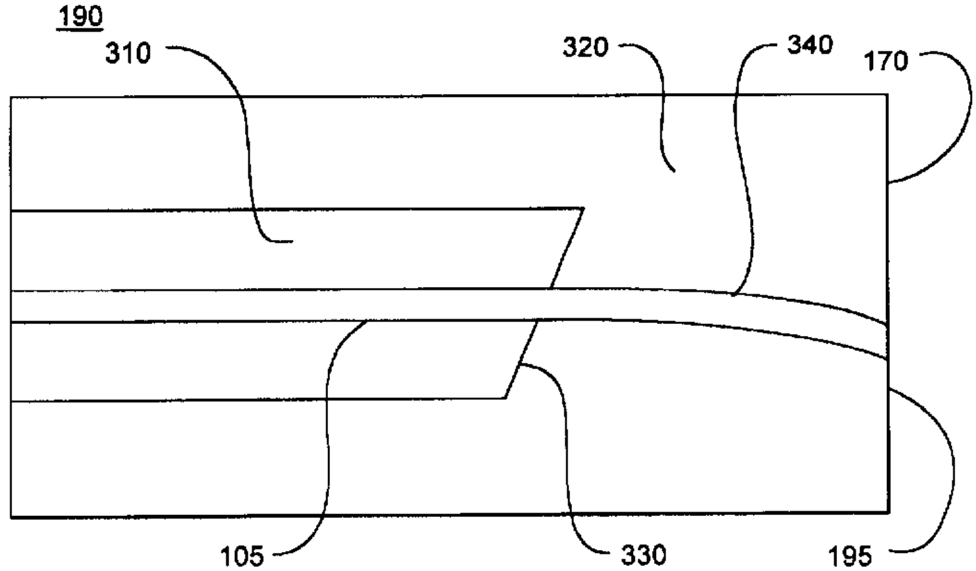


FIG. 3A

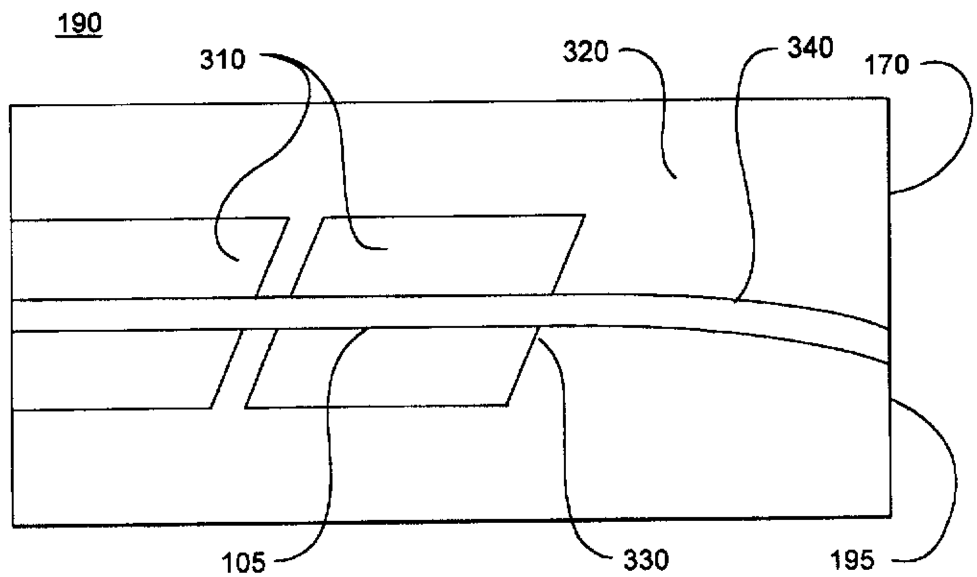


FIG. 3B

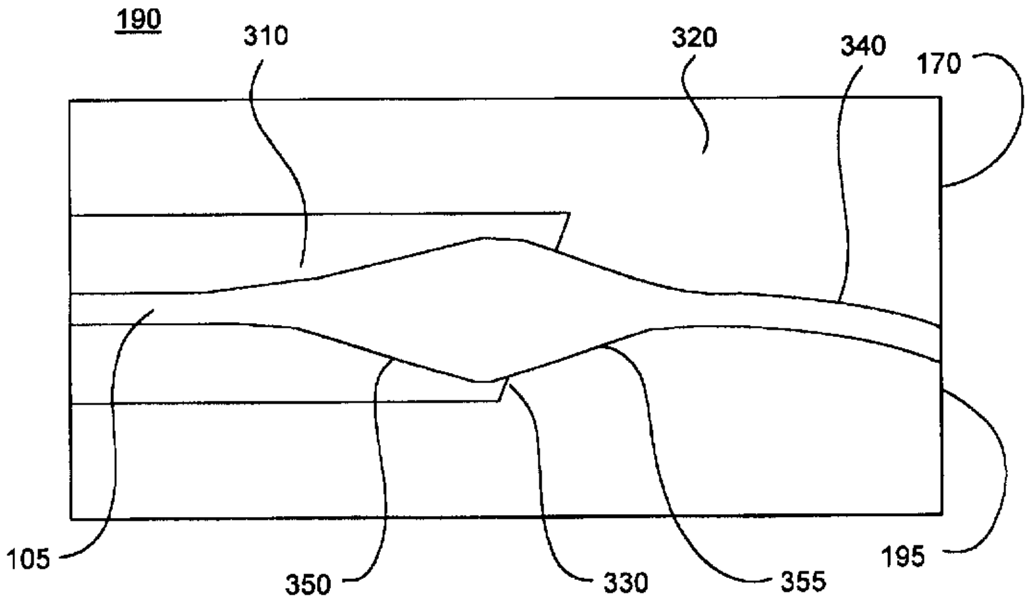


FIG. 3C

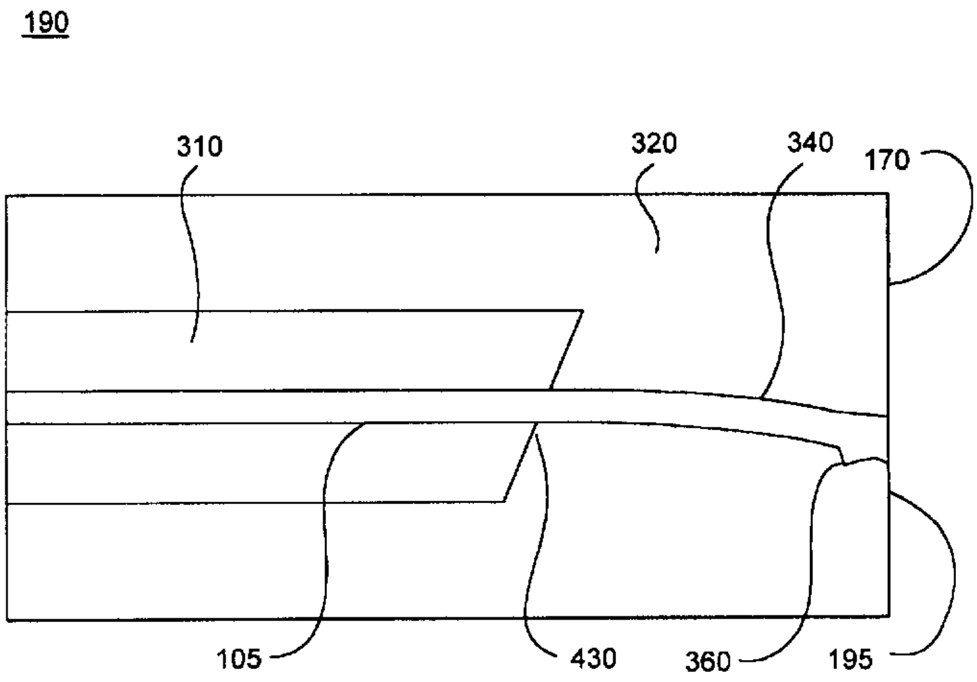


FIG. 3D

TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

This application is continuation-in-part and claims the benefit of priority of U.S. provisional application Ser. No. 60/152,072,filed Sep. 2, 1999, U.S. provisional application Ser. No. 60/152,049, filed Sep. 2, 1999, U.S. provisional application Ser. No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614/377, 09/614,895 (now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. No. 09/614,674, Ser. No. 09/614, 378, Ser. No. 09/614,376, Ser. No. 09/614,195, Ser. No. 09/614,665 and Ser. No. 09/614,224, which applications are filly incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

2. Brief Description of the Related Art

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure.

The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are non-uniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. 1B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. 2A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. 2B is a cross-sectional view of the FIG. 2 assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. 2C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. 3A is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. 3B is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. 3C is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a flared waveguide.

FIG. 3D is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. 1A shows a schematic of an embodiment of the invention. In FIG. 1A, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser

gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190** and output facet **195** are shown.

In FIG. 1A, laser assembly **100** comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, and back mirror **150** form a SODBR-type laser **180** in epitaxial structure **170**. The front and back mirrors define a laser cavity. Amplifier gain section **110** and a portion of waveguide **105** define optical amplifier **190**.

As shown in FIG. 1A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure **170** with the laser. Epitaxial structure **170** is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. 1 are gain sections **110** and **130**, phase control section **140** and mirrors **120** and **150**. An example of an optically passive section is the portion of waveguide **105** proximal to output facet **195**.

According to the invention, at least a portion of laser **180** and optical amplifier **190** share a common waveguide **105**. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. 1A, amplifier **190** is external to the resonant cavity of laser **180** formed by mirrors **120** and **150**. Moreover, amplifier gain section **110** is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. 1A, optical amplifier **190** has an active section and a passive section. The active section, amplifier gain section **110**, is substantially straight. The passive section of waveguide **105** is curved and intersects output facet **195** at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier **190** and laser **180**.

FIG. 1B shows a longitudinal cross section of a laser assembly **100** of FIG. 1A. In FIG. 1B, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190**, output facet **195**, p type semiconductor layer **125**, n-type semiconductor layer **115**, mirror sampling period **135**, offset quantum wells **145** and stop etch layer **155** are shown.

In FIG. 1B waveguide **105** is formed between p-type and n-type semiconductor layers **125** and **115**, respectively. Mirrors **120** and **150** are formed by sample gratings etched in waveguide **105** with sampling period **135**, as is well-understood in the art.

FIG. 1B illustrates the structure resulting from an offset quantum well technique for optically active and passive section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers **145** grown in a region offset from waveguide **105**. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer **155**. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. 2A–2C illustrate cross-sectional structures over a portion of laser assembly **100** (see FIG. 1) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. 2A illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. 1) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. 2A, optically passive section **210**, optically active section **220**, bandgap-shifted quantum wells **230**, active section quantum wells **240**, and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. 2A, different portions of waveguide **105** are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. 2B illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. 1) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. 2B, optically passive section **210**, optically active section **220**, disordered wells **250**, active section multiple quantum wells **260**, and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. 2B, different portions of waveguide **105**, sections **210** and **220**, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. 2C illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. 1) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. 2B, optically passive section **210**, optically active section **220**, active, butt-joint interface **270**, passive waveguide section **275**, active waveguide section **285** and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. 2B, active waveguide section **285** and passive waveguide section **275** are separated by a distinct large gradient butt-joint interface **270** as a result of the etch removal process.

FIGS. 3A–3D are plan views, illustrating different embodiments of optical amplifier **190** (see FIG. 1). In FIGS. 3A–3D optical amplifier **190**, waveguide **105**, epitaxial structure **170**, output facet **195**, active amplifier section **310**, passive amplifier section **320**, active-passive junction **330**, curved waveguide portion **340**, flared waveguide portions **350** and **355** and waveguide mode adapter **360** are shown.

In FIG. 3A, optical amplifier **190** has an active amplifier section **310** combined with a passive amplifier section **320**, where the passive amplifier section includes curved

waveguide portion **340**. The curved waveguide portion intersects output facet **195** at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction **330** is preferably oblique to a centerline of waveguide **105** so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction **330** substantially normal to a centerline of the waveguide.

FIG. **3B** shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. **3B**, the amplifier active section is segmented into two amplifier active sections **310** that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. **3C** shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion **350** increases the amplifier active volume as compared to the embodiment shown in FIG. **3A** and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section **355** to a narrow waveguide cross-section is positioned in the amplifier optically passive section **320** since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet **195**. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion **340**, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. **3C**, active-passive junction **330** is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. **3D** shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet **195** so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly **100** (see FIG. **1**) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A diode laser assembly, comprising:

substrate;

an epitaxal structure formed on the substrate;

a laser formed in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom; and

an amplifier formed in the epitaxial structure, at least a portion of the laser and amplifier sharing a common waveguide, the tunable laser output being coupled to the amplifier along the common waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflection from an output facet.

2. The laser assembly of claim **1** wherein the common waveguide has non-uniform optical properties along its centerline.

3. The laser assembly of claim **1** wherein the common waveguide has non-uniform cross-sectional area along its centerline.

4. The laser assembly of claim **1** wherein the common waveguide has non-uniform curvature along its centerline.

5. The laser assembly of claim **1** wherein the common waveguide has non-uniform optical properties normal to its centerline.

6. The assembly of claim **1**, wherein the amplifier includes at least one active region and at least one passive region.

7. The assembly of claim **6**, wherein the waveguide extends through an active region and a passive region.

8. The assembly of claim **7**, wherein a portion of the waveguide in the amplifier is curved.

9. The assembly of claim **7**, wherein at least a portion of the waveguide in a passive region of the amplifier is curved.

10. The assembly of claim **7**, wherein a portion of the waveguide in the amplifier is curved and the amplifier includes a flared waveguide section.

11. The assembly of claim **7**, wherein an interface between the active region and the passive region is oblique to a centerline of the waveguide.

12. The assembly of claim **7**, wherein an interface between the active region and the passive region is substantially normal to a centerline of the waveguide.

13. The assembly of claim **7**, wherein an end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

14. The assembly of claim **6**, wherein the waveguide includes a waveguide mode adapter.

15. The assembly of claim **6**, wherein the first active region has a oblique distal face.

16. The assembly of claim **1**, wherein the laser has a multi-active region gain medium.

17. The assembly of claim **1**, wherein the epitaxial structure has areas of differing optical properties.

18. The assembly of claim **1**, wherein the waveguide includes active section.

19. The assembly of claim **18**, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

20. The assembly of claim **18**, where the active section of the waveguide is positioned in the second active section of the amplifier.

21. The assembly of claim **1**, wherein at least a portion of the waveguide is non-parallel to an axis of the laser's cavity.

22. The assembly of claim 1, wherein the amplifier includes a plurality of independently controllable active regions.

23. The assembly of claim 22, wherein a first and a second active region are separated by a passive region.

24. The assembly of claim 23, wherein the first active region has a oblique distal face.

25. The assembly of claim 23, wherein the second active region has an oblique proximal face.

26. The assembly of claim 23, wherein the oblique distal face of the first active region is parallel to the oblique proximal face of the second active region.

27. The assembly of claim 23, wherein the second active region has a oblique distal face.

28. The assembly of claim 27, wherein the proximal face and the distal face of the second region are parallel.

29. The assembly of claim 1, wherein a width of the laser output is independent of a width of the waveguide at an output of the amplifier.

30. The assembly of claim 1, wherein the laser includes a mode selection element.

31. The assembly of claim 30, wherein the mode selection element is a controllable phase shifting element.

32. The assembly of claim 1, wherein the at least one of the first and second reflectors is tunable.

33. The assembly of claim 32, wherein at least one of the first and second reflectors is a distributed reflector.

34. The assembly of claim 32, wherein both of the first and second reflectors are distributed reflectors.

35. The assembly of claim 32, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

36. The assembly of claim 32, wherein each of the first and second reflectors is a distributed Bragg reflector.

37. The assembly of claim 32, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

38. The assembly of claim 32, wherein a maximum reflectivity of each of the first and second reflectors is tunable.

39. The assembly of claim 32, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

40. The assembly of claim 32, wherein the laser includes an attenuator and at least one amplifier positioned outside of the laser.

41. The assembly of claim 32, wherein the laser includes a controllable amplifier positioned outside of the laser.

42. The assembly of claim 32, wherein the laser includes a controllable attenuator positioned outside of the laser.

43. The assembly of claim 1, wherein at least a portion of the waveguide is flared.

44. The assembly of claim 43, wherein a flared portion of the waveguide is in an active region.

45. The assembly of claim 43, wherein a flared portion of the waveguide is in a passive region.

46. The assembly of claim 1, wherein the optical signal is tunable within a range of at least 15 nm.

47. A diode laser assembly, comprising:

a first semiconductor layer in an epitaxial structure;

a second semiconductor layer formed in the epitaxial structure, the first and second semiconductor layers having different dopings;

a waveguide layer formed between the first and second semiconductor layers, the first waveguide layer including a waveguide, a first reflector and a second reflector;

an optically active medium disposed between the first and second reflectors, the first and second reflectors defining a laser cavity and producing a tunable laser output; and

an amplifier formed in the epitaxial structure, wherein the laser cavity and the amplifier are optically aligned, the tunable laser output being coupled into the amplifier along the waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

48. The assembly of claim 47, wherein a distal portion of the waveguide in the amplifier is curved.

49. The assembly of claim 47, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

50. The assembly of claim 47, wherein at least a portion of the waveguide is non-parallel to an axis of the laser cavity.

51. The assembly of claim 47, wherein at least a portion of the waveguide is flared.

52. The assembly of claim 47, wherein the waveguide includes an active section.

53. The assembly of claim 52, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

54. The assembly of claim 52, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

55. The assembly of claim 47, wherein the amplifier includes a first active region and a passive region.

56. The assembly of claim 55, wherein the amplifier includes a second active region.

57. The assembly of claim 55, wherein the first and second active regions are separated by a passive region.

58. The assembly of claim 57, wherein the first active region has an oblique distal face.

59. The assembly of claim 58, wherein the second active region has au oblique proximal face.

60. The assembly of claim 59, wherein the oblique distal face of the first active region is parallel to the oblique proximal face of the second active region.

61. The assembly of clam 59, wherein the second active region has an oblique distal face.

62. The assembly of claim 61, wherein the proximal face and the distal face of the second region are parallel.

63. The assembly of claim 55, wherein the waveguide extends through at least a portion of the amplifier.

64. The assembly of claim 55, wherein the first active region has an oblique distal face.

65. The assembly of claim 55, wherein the waveguide extends through the first active region and the passive region.

66. The assembly of claim 55, wherein the waveguide includes a mode adapter.

67. The assembly of claim 47, wherein at least one of the first and second reflectors is tunable.

68. The assembly of claim 67, wherein both of the first and second reflectors is a distributed reflector.

69. The assembly of claim 67, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

70. The assembly of claim 67, wherein each of the first and second reflectors is a distributed Bragg reflector.

71. The assembly of claim 67, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

72. The assembly of claim 67, wherein a maximum reflectivity of each of the first and second reflectors is tunable.

73. The assembly of claim 67, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

74. The assembly of claim 67, wherein the laser includes a controllable amplifier positioned outside of the laser.

75. The assembly of claim 67, wherein the laser includes a controllable attenuator positioned outside of the laser.

76. The assembly of claim 67, wherein the laser includes an attenuator and at least one amplifier positioned outside of the resonant cavity.

77. The assembly of claim 67, wherein at least one of the first and second reflectors is a distributed reflector.

78. The assembly of claim 47, wherein the laser includes a mode selection element.

79. The assembly of claim 78, wherein the mode selection element is a controllable phase shifting element.

80. The assembly of claim 47, wherein the optical signal is tunable within a range of at least 15 nm.

81. The assembly of claim 47, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

82. The assembly of claim 47, wherein the epitaxial structure has areas of differing optical properties.

* * * * *

EXHIBIT 3

US006687278B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.:** **US 6,687,278 B1**
(45) **Date of Patent:** **Feb. 3, 2004**

(54) **METHOD OF GENERATING AN OPTICAL SIGNAL WITH A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

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(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 211 days.

(21) Appl. No.: **09/614,665**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, now Pat. No. 6,580,739, and a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, and a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, now Pat. No. 6,614,819, and a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, now Pat. No. 6,574,259, and a continuation-in-part of application No. 09/614,375, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,224, filed on Jul. 12, 2000.

(60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) **Int. Cl.**[7] **H01S 5/026**

(52) **U.S. Cl.** **372/50**; 372/20; 438/22

(58) **Field of Search** 372/50, 20; 438/22

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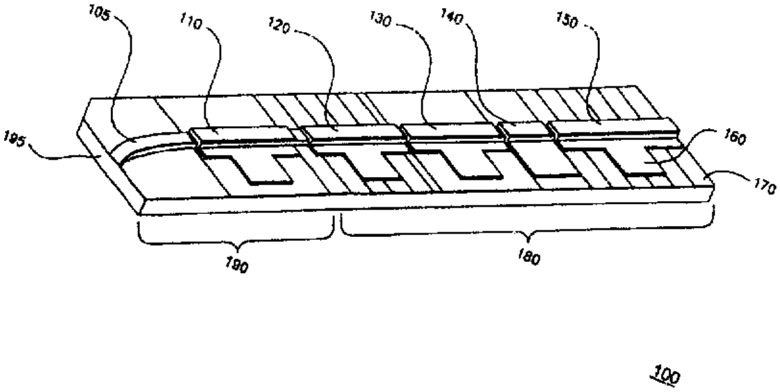
Primary Examiner—Quyen Leung
Assistant Examiner—Jeffrey Zahn
(74) *Attorney, Agent, or Firm*—Gates & Cooper LLP

(57) **ABSTRACT**

A method of generating an optical signal provides a diode laser assembly including an epitaxial structure formed on a substrate. A laser and an amplifier are formed in the epitaxial structure. At least a portion of the laser and amplifier share a common waveguide. A tunable laser output is produced from the laser. The laser output is coupled into the amplifier along the common waveguide. An optical signal is generated from the amplifier.

26 Claims, 7 Drawing Sheets



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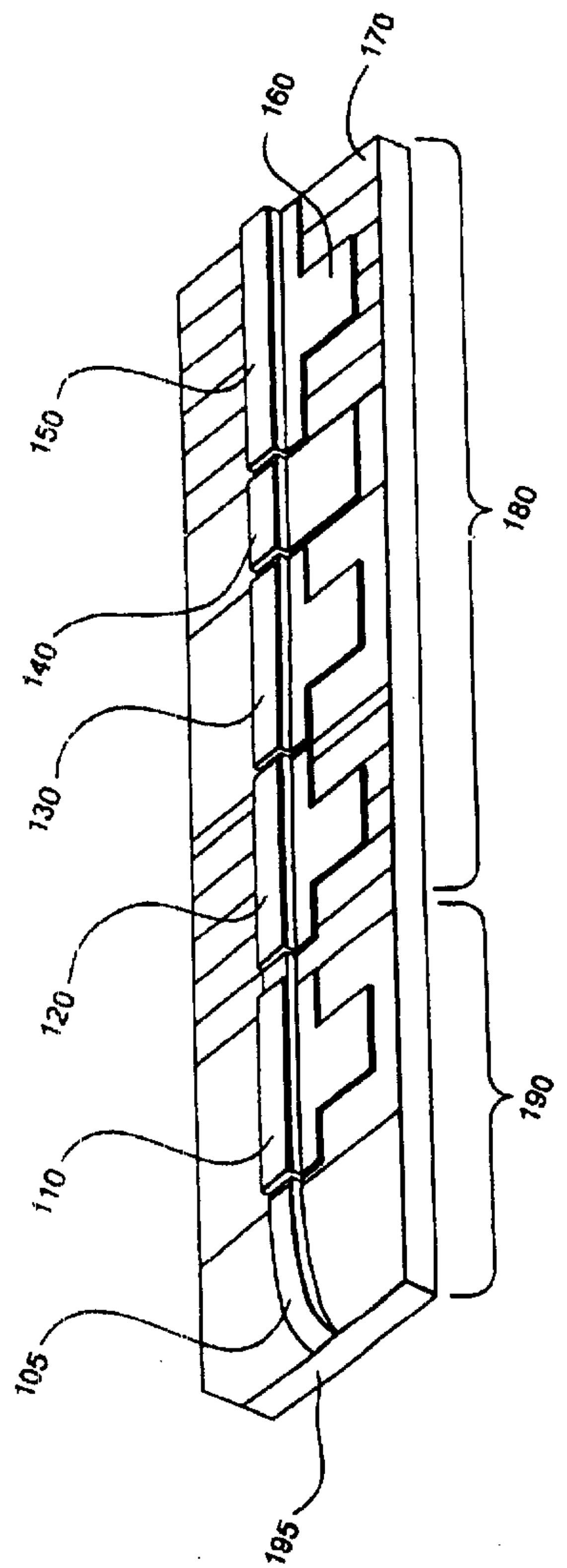

FIG. 1A

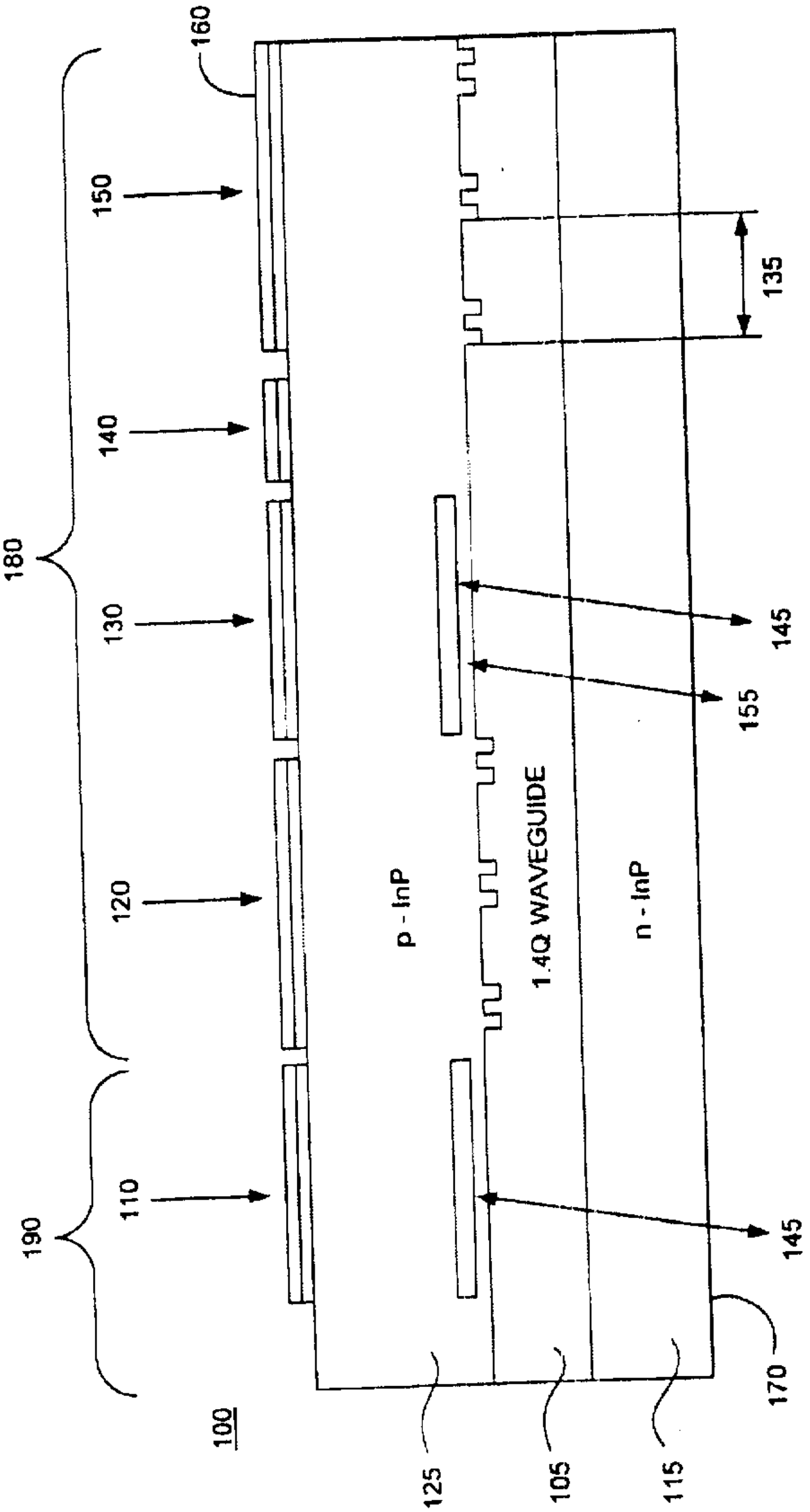
160
150
140
130
120
110
180
190
135
145
155
145
p - InP
1.4Q WAVEGUIDE
n - InP
100
125
105
115
170

FIG. 1B

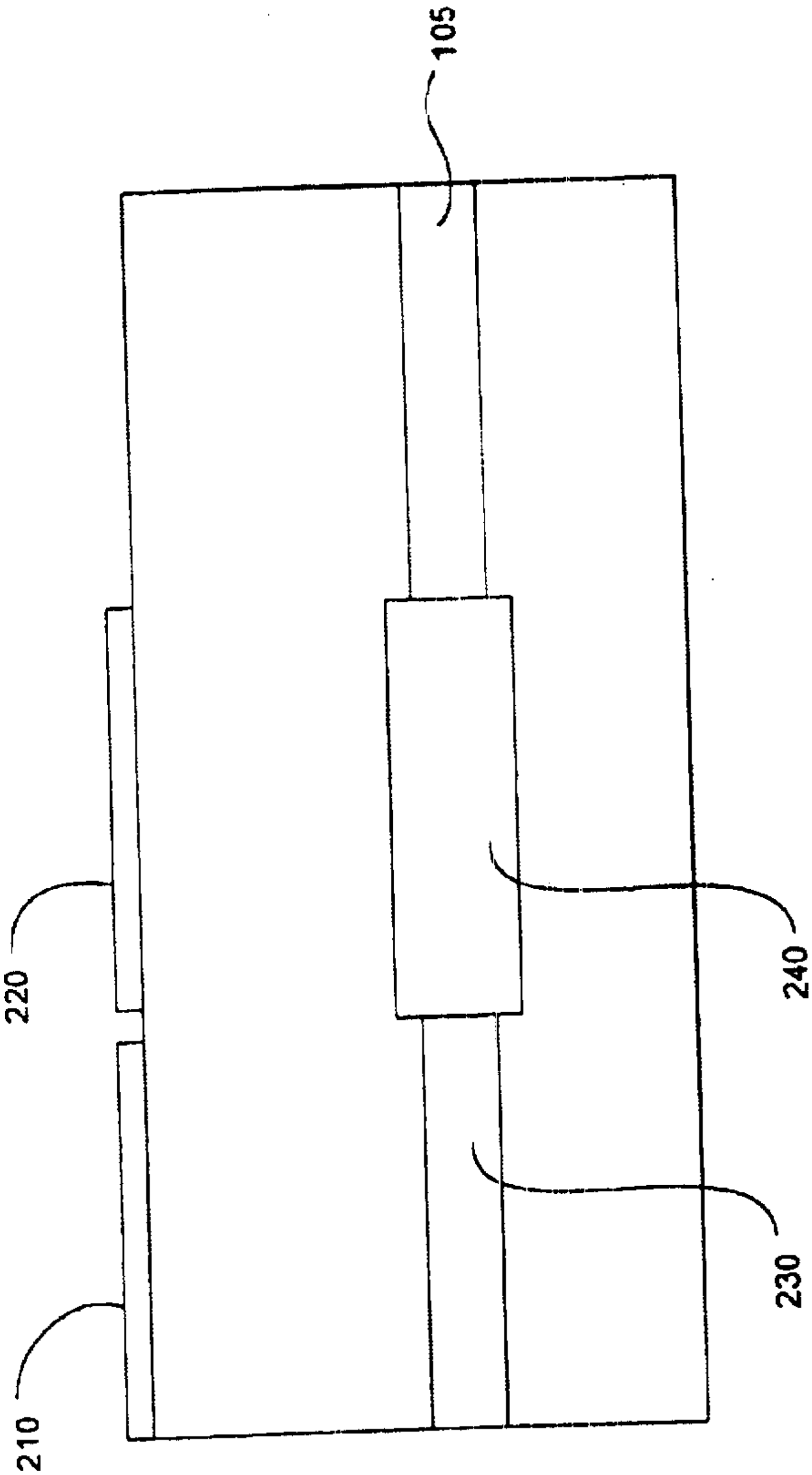

FIG. 2A

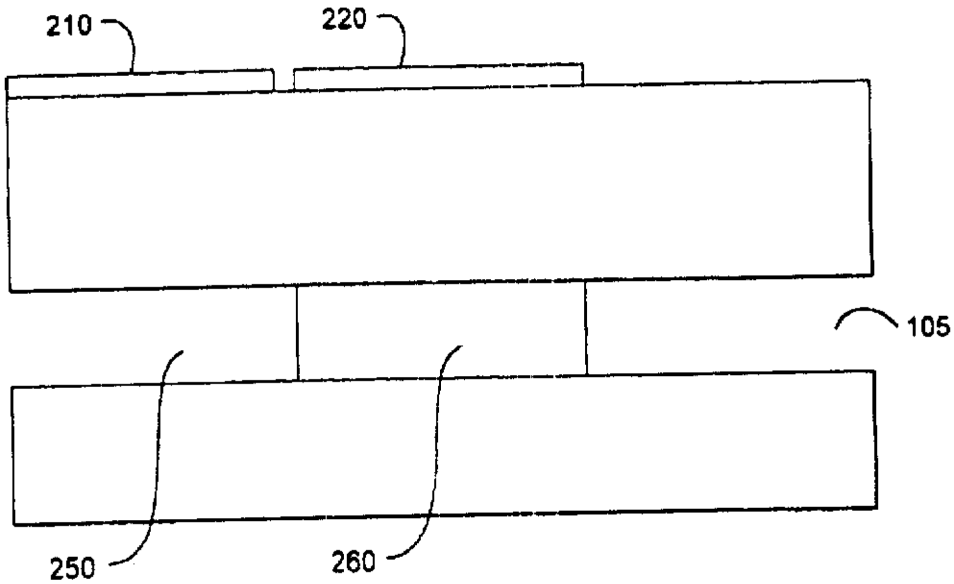

FIG. 2B

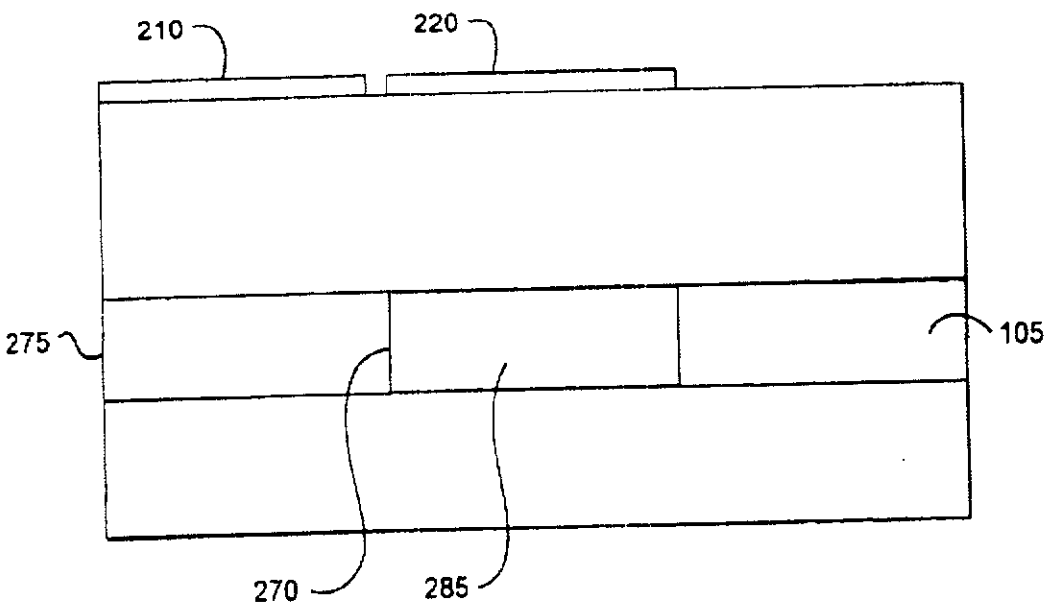

FIG. 2C

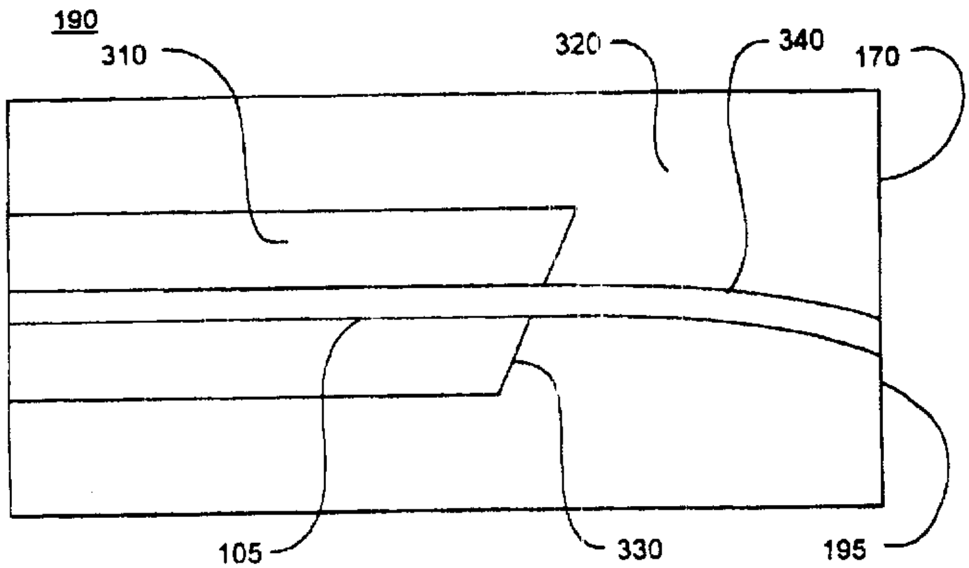

FIG. 3A

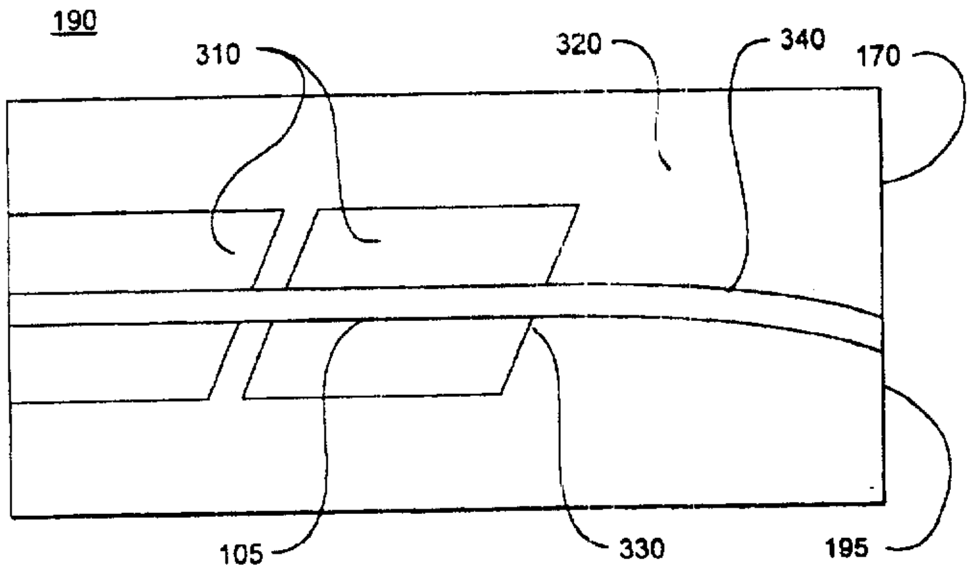

FIG. 3B

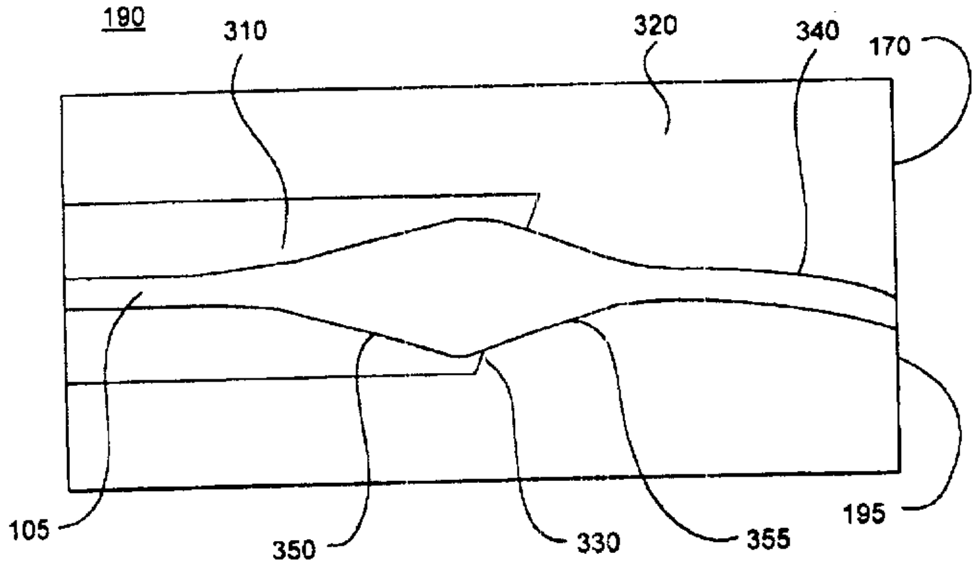

FIG. 3C

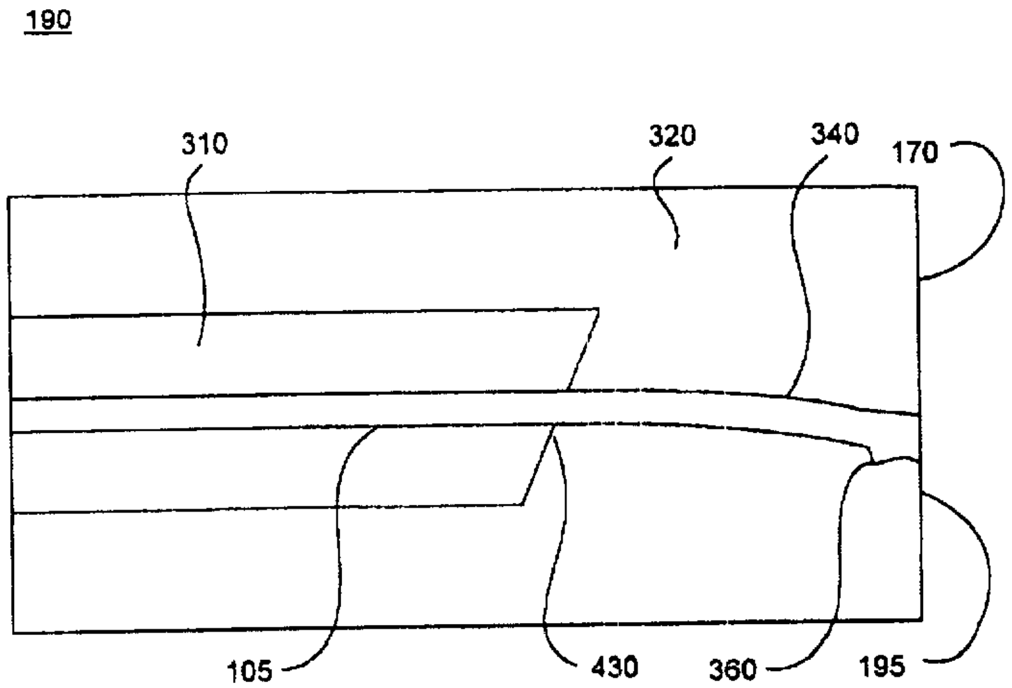

FIG. 3D

METHOD OF GENERATING AN OPTICAL SIGNAL WITH A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part and claims the benefit of priority of U.S. Provisional Application Ser. No. 60/152,072, filed Sep. 2, 1999, U.S. Provisional Application Ser. No. 60/152,049, filed Sep. 2, 1999, U.S. Provisional Application Ser. No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614/377 now U.S. Pat. No. 6,580,739, **09/614,895**(now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. Nos. 09/614,674, 09/614,378, 09/614,376 now U.S. Pat. No. 6,614,819, **09/614,195**now U.S. Pat. No. 6,574,259, **09/614,375**and 09/614,224, filed on the same date as this application, which applications are fully incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

BRIEF DESCRIPTION OF THE RELATED ART

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure. The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are non-uniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. 1B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. 2A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. 2B is a cross-sectional view of the FIG. 2 assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. 2C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. 3A is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. 3B is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. 3C is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a flared waveguide.

FIG. 3D is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. 1A shows a schematic of an embodiment of the invention. In FIG. 1A, laser assembly **100**, waveguide **105**,

amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190** and output facet **195** are shown.

In FIG. 1A, laser assembly **100** comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, and back mirror **150** form a SGDBR-type laser **180** in epitaxial structure **170**. The front and back mirrors define a laser cavity. Amplifier gain section **110** and a portion of waveguide **105** define optical amplifier **190**.

As shown in FIG. 1A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure **170** with the laser. Epitaxial structure **170** is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. 1 are gain sections **110** and **130**, phase control section **140** and mirrors **120** and **150**. An example of an optically passive section is the portion of waveguide **105** proximal to output facet **195**.

According to the invention, at least a portion of laser **180** and optical amplifier **190** share a common waveguide **105**. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. 1A, amplifier **190** is external to the resonant cavity of laser **180** formed by mirrors **120** and **150**. Moreover, amplifier gain section **110** is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. 1A, optical amplifier **190** has an active section and a passive section. The active section, amplifier gain section **110**, is substantially straight. The passive section of waveguide **105** is curved and intersects output facet **195** at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier **190** and laser **180**.

FIG. 1B shows a longitudinal cross section of a laser assembly **100** of FIG. 1A. In FIG. 1B, laser assembly **100**, waveguide **105**, amplifier gain section **110**, front resonator mirror **120**, laser gain section **130**, laser phase control section **140**, back mirror **150** and electrical contact **160**, epitaxial structure **170**, laser **180**, optical amplifier **190**, output facet **195**, p type semiconductor layer **125**, n-type semiconductor layer **115**, mirror sampling period **135**, offset quantum wells **145** and stop etch layer **155** are shown.

In FIG. 1B waveguide **105** is formed between p-type and n-type semiconductor layers **125** and **115**, respectively. Mirrors **120** and **150** are formed by sample gratings etched in waveguide **105** with sampling period **135**, as is well-understood in the art.

FIG. 1B illustrates the structure resulting from an offset quantum well technique for optically active and passive section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers **145** grown in a region offset from waveguide **105**. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer **155**. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. 2A–2C illustrate cross-sectional structures over a portion of laser assembly **100** (see FIG. 1) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. 2A illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. 1) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. 2A, optically passive section **210**, optically active section **220**, bandgap-shifted quantum wells **230**, active section quantum wells **240**, and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. 2A, different portions of waveguide **105** are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. 2B illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. 1) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. 2B, optically passive section **210**, optically active section **220**, disordered wells **250**, active section multiple quantum wells **260**, and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. 2B, different portions of waveguide **105**, sections **210** and **220**, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. 2C illustrates a cross-sectional structure over a portion of laser assembly **100** (see FIG. 1) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. 2B, optically passive section **210**, optically active section **220**, active, butt-joint interface **270**, passive waveguide section **275**, active waveguide section **285** and waveguide **105** (see FIGS. 1A–1B) are shown. In FIG. 2B, active waveguide section **285** and passive waveguide section **275** are separated by a distinct large gradient butt-joint interface **270** as a result of the etch removal process.

FIGS. 3A–3D are plan views, illustrating different embodiments of optical amplifier **190** (see FIG. 1). In FIGS. 3A–3D optical amplifier **190**, waveguide **105**, epitaxial structure **170**, output facet **195**, active amplifier section **310**, passive amplifier section **320**, active-passive junction **330**, curved waveguide portion **340**, flared waveguide portions **350** and **355** and waveguide mode adapter **360** are shown.

In FIG. 3A, optical amplifier **190** has an active amplifier section **310** combined with a passive amplifier section **320**, where the passive amplifier section includes curved

waveguide portion **340**. The curved waveguide portion intersects output facet **195** at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction **330** is preferably oblique to a centerline of wave guide **105** so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction **330** substantially normal to a centerline of the waveguide.

FIG. **3B** shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. **3B**, the amplifier active section is segmented into two amplifier active sections **310** that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. **3C** shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion **350** increases the amplifier active volume as compared to the embodiment shown in FIG. **3A** and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section **355** to a narrow waveguide cross-section is positioned in the amplifier optically passive section **320** since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet **195**. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion **340**, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. **3C**, active-passive junction **330** is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. **3D** shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet **195** so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly **100** (see FIG. **1**) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A method of generating an optical signal, comprising:

providing a diode laser assembly including an epitaxial structure formed on a substrate, a laser and an amplifier formed in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom, at least a portion of the laser and an amplifier sharing a common waveguide formed in the epitaxial structure, wherein at least a portion of the common waveguide is curved to reduce reflections from an output facet;

coupling the laser output into the amplifier along the common waveguide; and

generating an optical signal from the amplifier in response to the coupled laser output.

2. The method of claim **1**, wherein the optical signal is generated while controlling an intensity of the laser output and maintaining a constant laser wavelength.

3. The method of claim **1**, wherein the curved portion of the common waveguide reduces an amount of light reflecting into the amplifier and laser.

4. The method of claim **1**, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet, so that it is more closely matched to a mode in an optical fiber.

5. The method of claim **1**, wherein laser output is tunable over a tuning range while maintaining a substantially constant output power.

6. The method of claim **1**, wherein laser output is tunable over a tuning range of at least 15 nm while maintaining a substantially constant output power.

7. The method of claim **1**, wherein the optical signal is generated while alternating a propagation direction of the laser output within the amplifier.

8. The method of claim **1**, wherein the optical signal is generated while minimizing back reflections into the laser.

9. The method of claim **1**, wherein the optical signal is generated while alternating at least one optical mode in the amplifier.

10. The method of claim **9**, wherein altering the optical modes is an adiabatic mode expansion.

11. The method of claim **1**, wherein the optical signal is generated while selectively exciting waveguide modes in the amplifier.

12. The method of claim **1**, wherein the curved portion of the common waveguide intersects the output facet at an oblique angle.

13. The method of claim **12**, wherein both the curved portion of the common waveguide and the oblique angle reduce an amount of light reflecting from the output facet back into the amplifier and laser.

14. A method of generating an optical signal, comprising:

providing a diode laser assembly including first and second semiconductor layers in an epitaxial structure, a waveguide formed between the first and second semiconductor layers in the epitaxial structure, and a laser and an amplifier formed in the epitaxial structure, the laser including a gain section and a phase section each being positioned between two grating sections to pro-

duce a tunable laser output therefrom, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet;

coupling the laser output into the amplifier along the waveguide;

propagating the laser output in a tapered section of the waveguide in the amplifier to increase saturated output power; and

generating an optical signal from the amplifier in response to the propagated laser output.

15. The method of claim **14**, wherein the optical signal is generated while controlling an intensity of the laser output and maintaining a constant laser wavelength.

16. The method of claim **14**, wherein the laser output is tunable over a tuning range while maintaining a substantially constant output power.

17. the method of claim **14**, wherein the laser output is tunable over a tuning range of at least 15 nm while maintaining a substantially constant output power.

18. The method of claim **14**, wherein the optical signal is generated while alternating a propagation direction of the laser output within the amplifier.

19. The method of claim **14**, wherein the optical signal is generated while minimizing back reflections into the laser.

20. The method of claim **14**, wherein the optical signal is generated while altering at least one optical mode in the amplifier.

21. The method of claim **20**, wherein altering the optical modes is an adiabatic mode expansion.

22. The method of claim **14**, wherein the optical signal is generated while selectively exciting waveguide modes in the amplifier.

23. The method of claim **14**, wherein the curved portion of the waveguide reduces an amount of light reflecting into the amplifier and laser.

24. The method of claim **14**, wherein the curved portion of the waveguide intersects the output facet at an oblique angle.

25. The method of claim **24**, wherein both the curved portion of the waveguide and the oblique angle reduce an amount of light reflecting from the output facet back into the amplifier and laser.

26. The method of claim **14**, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet, so that it is more closely matched to a mode in an optical fiber.

* * * * *

JS 44 - CAND (Rev. 11/04)

CIVIL COVER SHEET

The JS-44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON PAGE TWO.)

I. (a) PLAINTIFFS

BOOKHAM, INC., a Delaware corporation

DEFENDANTS

JDS UNIPHASE CORPORATION, a Delaware corporation, AGILITY COMMUNICATIONS, INC., a Delaware corporation, and DOES 1-10

ADR

(b) COUNTY OF RESIDENCE OF FIRST LISTED PLAINTIFF Santa Clara
(EXCEPT IN U.S. PLAINTIFF CASES)

COUNTY OF RESIDENCE OF FIRST LISTED DEFENDANT
(IN U.S. PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED.

(c) ATTORNEYS (FIRM NAME, ADDRESS, AND TELEPHONE NUMBER)
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ATTORNEYS (IF KNOWN)

C08 01275 HRL

II. BASIS OF JURISDICTION (PLACE AN 'X' IN ONE BOX ONLY)

- [ ] 1 U.S. Government Plaintiff
- [X] 3 Federal Question (U.S. Government Not a Party)
- [ ] 2 U.S. Government Defendant
- [ ] 4 Diversity (Indicate Citizenship of Parties in Item III)

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- 151 Medicare Act
- 152 Recovery of Defaulted Student Loans (Excl Veterans)
- 153 Recovery of Overpayment of Veteran's Benefits
- 160 Stockholders Suits
- 190 Other Contract
- 195 Contract Product Liability
- 196 Franchise

REAL PROPERTY
- 210 Land Condemnation
- 220 Foreclosure
- 230 Rent Lease & Ejectment
- 240 Torts to Land
- 245 Tort Product Liability
- 290 All Other Real Property

TORTS

PERSONAL INJURY
- 310 Airplane
- 315 Airplane Product Liability
- 320 Assault Libel & Slander
- 330 Federal Employers Liability
- 340 Marine
- 345 Marine Product Liability
- 350 Motor Vehicle
- 355 Motor Vehicle Product Liability
- 360 Other Personal Injury

PERSONAL INJURY
- 362 Personal Injury Med Malpractice
- 365 Personal Injury Product Liability
- 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- 370 Other Fraud
- 371 Truth in Lending
- 380 Other Personal Property Damage
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CIVIL RIGHTS
- 441 Voting
- 442 Employment
- 443 Housing
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- 445 Amer w/ disab - Empl
- 446 Amer w/ disab - Other

PRISONER PETITIONS
- 510 Motion to Vacate Sentence
- Habeas Corpus:
- 530 General
- 535 Death Penalty
- 540 Mandamus & Other
- 550 Civil Rights
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FORFEITURE/PENALTY
- 610 Agriculture
- 620 Other Food & Drug
- 625 Drug Related Seizure of Property 21 USC 881
- 630 Liquor Laws
- 640 RR & Truck
- 650 Airline Regs
- 660 Occupational Safety/Health
- 690 Other

LABOR
- 710 Fair Labor Standards Act
- 720 Labor/Mgmt Relations
- 730 Labor/Mgmt Reporting & Disclosure Act
- 740 Railway Labor Act
- 790 Other Labor Litigation
- 791 Empl. Ret. Inc. Security Act

BANKRUPTCY
- 422 Appeal 28 USC 158
- 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- 820 Copyrights
- [X] 830 Patent
- 840 Trademark

14

SOCIAL SECURITY
- 861 HIA (1395ff)
- 862 Black Lung (923)
- 863 DIWC/DIWW (405(g))
- 864 SSID Title XVI
- 865 RSI (405(g))

FEDERAL TAX SUITS
- 870 Taxes (US Plaintiff or Defendant)
- 871 IRS - Third Party 26 USC 7609

OTHER STATUTES
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- 410 Antitrust
- 430 Banks and Banking
- 450 Commerce/ICC Rates/etc.
- 460 Deportation
- 470 Racketeer Influenced and Corrupt Organizations
- 480 Consumer Credit
- 490 Cable/Satellite TV
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- 850 Securities/Commodities/Exchange
- 875 Customer Challenge 12 USC 3410
- 891 Agricultural Acts
- 892 Economic Stabilization Act
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VII. REQUESTED IN COMPLAINT: [ ] CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23 DEMAND $

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